ECONOMIC GEOLOGY

WITH WHICH IS INCORPORATED

THE AMERICAN GEOLOGIST

VOL. I JULY–AUGUST, 1906 No. 7

LOS PILARES MINE, NACOZARI, MEXICO.

SAMUEL FRANKLIN EMMONS.

LOCATION AND GEOLOGY.

Seventy-five miles south of the International Boundary, in the Valley of the Moctezuma River, in Sonora, Mexico, lies the picturesquely situated town of Nacozari, which has grown up during the last six or seven years around the concentration works that dress the copper ores from the neighboring mine known as Los Pilares.

This mine, whose economic importance may be gauged by the fact that it has already produced over 600,000 tons of copper ore, is one of the many copper properties in the southwest owned and managed by the Phelps-Dodge & Company interests.

The present sketch is the result of a two days' examination of the mine made in November, 1905, when the writer was the guest of Mr. James Douglas, Jr., General Manager of the property, by whose courtesy he was given every facility for its study. Although he feels some hesitation in presenting in these pages the result of so brief an examination, it has, nevertheless, seemed to him that the facts ascertained with regard to the occurrence of the ore present sufficient novelty and interest to justify their publication in spite of the uncertainty that still obtains with regard to certain features of the general geology.

Copyright, 1906, by Economic Geology Publishing Company.

Like many parts of Mexico, the region is one in which the rocks are prevailingly igneous, and apparently of comparatively recent age. Thus, in the 75-mile railroad ride from Douglas, Arizona, to Nacozari, following up the Valley of the Fronteras River and down the narrow gorge of the Moctezuma, the only rocks whose character could be determined, were eruptive tuffs and breccias, generally showing bedded structure, and not very deeply eroded.

The town of Nacozari is situated on the west side of a small, deeply incised river valley surrounded by irregularly distributed hills that form part of the northern watershed of the Yaqui River, the most important river system of the State of Sonora. The only rocks of distinctly sedimentary origin visible from the town stand out in sharply curved outcrops on the face of a high ridge some miles to the northwest, their sedimentary character being indicated not only by the folds into which they are compressed, but also by the limekilns at the base of the outcrops.

Against the steep wall of the valley, opposite the town, are situated the concentration works from whose upper level runs a narrow gauge railway that connects them with the Los Pilares mine, about 5 miles to the southeast.

In frequent journeyings to and fro, on this railway, which winds in and out across the southward trending spurs and ravines in a bewildering series of zig-zags, it could be seen that these spurs are made up of an alternation of darker and lighter eruptive breccias and tuffs, the former generally showing some bedded structure. As the abrupt changes from one rock to another evidently mark fault rather than eruptive contacts no definite idea could be formed as to their relative age, though the general impression received here, and elsewhere, was that the lighter colored and more acid rocks were intrusive in, and hence later than, the darker.

The Los Pilares mine is situated on a northeast and southwest spur that runs athwart the end of the steam railway. The tracks of the latter, however, continue in a mile-long tunnel that runs nearly through the spur, and is operated by electric locomotives. At the further extremity of the tunnel is the main working shaft

that rises vertically 600 feet, reaching the surface on the southeast slope of the spur known as Los Pilares Mountain. From this shaft levels run at 100-foot intervals into the various stopes of the mine, and ore chutes connect the different levels with great ore bins in the rock at the tunnel, or 700-foot level. As thus opened, the ore, once broken down in the stopes of the mine, is moved mechanically with a minimum of hand labor. From the ore bin in the mine it passes into the narrow-gauge cars which transport it to the ore bins at the concentrator, and after dressing, the concentrates pass into standard gauge cars to be transmitted to the ore beds of the great smelter at Douglas, Arizona.

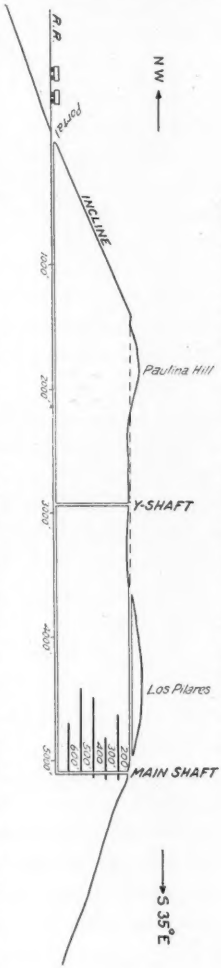

FIG. 44. Profile of Los Pilares Ridge on plane of tunnels and shaft.

The accompanying diagrammatic section through the hill on the line of the tunnel (Fig. 44) will give an idea of the relative position of the various workings. At 300 feet from the portal of the tunnel a vertical shaft rises to the surface, known as the Y shaft, possibly because it stands at the head of a secondary ravine that divides the spur into two parts. Of these two, the first, or northwestern, is known as Paulina Hill, while the further one is the Pilares Mountain proper. Through the top of the latter, on the so-called 100-foot level, runs a tunnel 1,300 feet long through which the ore was formerly transmitted from the working shaft to the head of an incline immediately over the portal or entrance to the present tunnel. The name of the mine is derived from projecting columns, or pillars, of

gossan on the summit of the hill about 100 feet above the upper tunnel level.

Country Rocks.—The rock forming the mass of Paulina Hill, as seen in its fresh condition at the portal of the tunnel, is a fine-grained andesite with latite tendency. Even in the freshest specimens, however, the feldspars are much altered and sericitized and the basic-silicates no longer recognizable. The alteration products are largely sericite and chlorite with some calcite. Its dark reddish-purple color is due to considerable amount of microscopic magnetite and hematite with possibly some ilmenite.[1] A little pyrite is also seen in the groundmass. The rock is in great part an eruptive breccia in which the matrix and enclosing fragments are of the same material, and it often shows a distinctly bedded structure.

The rock which forms the mass of Pilares Mountain beyond the Y shaft has a good deal of the external habit in color, weathering, etc., of a rhyolite, yet it shows neither flow structure nor quartz phenocrysts. The general field impression was that it is intrusive in the andesite breccia, yet no eruptive contacts were found by which this could be proved. Where unbroken, it has the general appearance of a massive, homogeneous rock, yet in some specimens a favorable light shows an original breccia structure which is also visible under the microscope. Microscopical examination shows that it is greatly silicified and sericitized. The feldspar phenocrysts are in great measure altered beyond determination, but both orthoclase and plagioclase are seen to be present. In the groundmass secondary quartz occurs, both as interlocking grains, and in fine veins. In the specimens taken from near the surface the little quartz veins have been cracked and the cracks filled with specular iron. The rock is petrographically defined as a quartz monzonite, if intrusive, though from a study of the average specimens Mr. Woolsey was inclined to think that it might be a highly altered and silicified variety of the Paulina andesite.

[1] The microscopic examination of thin sections of the specimens gathered was kindly made by Mr. Lester H. Woolsey and Mr. Waldemar Lindgren.

A diabase of distinctly later age traverses this monzonite. It is a dense, dark colored rock which in its fresher condition shows phenocrysts of feldspar. The microscope shows it to be a plagioclase rock of even, holocrystalline texture, which contains augite and some hornblende, and as decomposition products calcite, chlorite, and serpentine. A little secondary quartz in fine veins, but no pyrite, was found.

ORE DEPOSITS.

Character of the Ore.—The ore of the Los Pilares is remarkably simple and uniform, both in structure and composition. It is essentially a breccia of which pyrite, chalcopyrite, and quartz constitute the original cementing material, for, although much of the more massive rock is more or less impregnated with metallic sulphides, this impregnation has thus far proved commercially negligible.

Beside copper, iron, and sulphur, it contains practically no other metal. In some places there is a very little zinc, but no lead is known to exist. There is a trace of gold and less than an ounce of silver to the ton. Arsenic may be present in small amount, but has not been determined. The primary ore minerals are pyrite and chalcopyrite, the products of secondary enrichment being bornite and chalcocite, the former apparently in the larger proportion. In the gossan, as is often the case in arid regions, the limonite is almost entirely altered to specular iron. In the 1300-foot tunnel, at the 100-foot level, which is within the oxidized zone, only slight traces of pyrite were found, and, though its copper values had been leached out, the ore still retained its characteristic breccia structure, and at a little distance might have been mistaken for the normal copper ore.

The outward appearance of the ore is most striking, owing to the strong color contrast between the brass-yellow, iridescent purple, or blue-black, of the metallic cement, and the white rock fragments, and its singularity is heightened by the peculiar shape of a large proportion of these fragments which resemble a mass of broken potsherds, being relatively thin, often curved, and

shell-shaped. In the average ore these are mixed in the greatest confusion with a lesser proportion of fragments of other forms, generally angular, sometimes slightly rounded, and varying in size from a pin head to masses several feet in diameter. Figure 2 is a photographic reproduction of an average specimen of rich

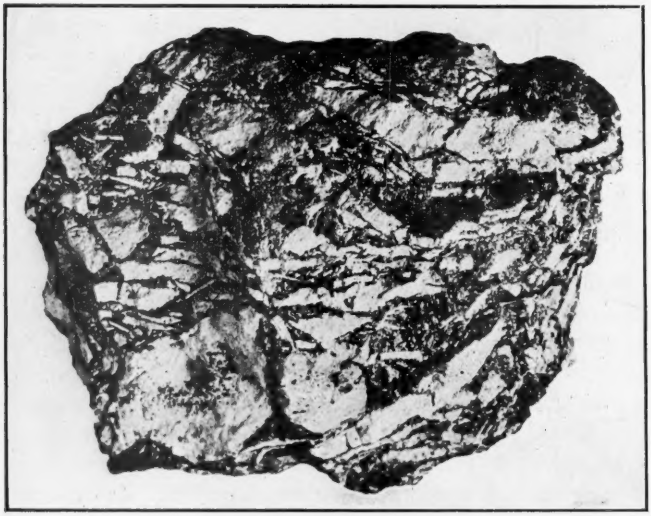

FIG. 45. Specimen of rich breccia ore. Light parts are fragments of country rock; darker part is metallic cement.

ore in which the metallic matrix appears to consist of about equal proportions of bright pyrite, chalcopyrite, and bornite, with a relatively smaller amount of dull-black chalcocite. Closer examination, however, shows that the bornite and chalcocite form only a thin veneer over the faces of the pyrite, and that the latter forms the mass of the filling of the larger interstices, and, in rare cases, develops into well-defined crystals. For the most part, pyrite is massive or mixed with finely granular quartz. Quartz often forms a thin layer on the outer surface of the rock fragments, in which case their interior is mostly barren of

metallic sulphides. The larger angular fragments, as shown in the specimen, have, however, sometimes a slight interior impregnation of pyrite.

Throughout the ore mass one frequently finds bomb-like masses of dense country rock, practically free from metallic impregnation, in size from a small cannon ball upwards, and which when freed from their matrix often form an almost perfect sphere. These furnish an explanation of the thin sherd-like fragments in the breccia, for it is seen that their outer surface has flaked off in thin concentric layers like the leaves of an onion, quartz and metallic sulphides having filled in the gradually enlarging cracks between successive layers, thus showing that the ore solutions have produced an effect in the interior of this rock mass similar to that which weathering does upon certain igneous rocks near

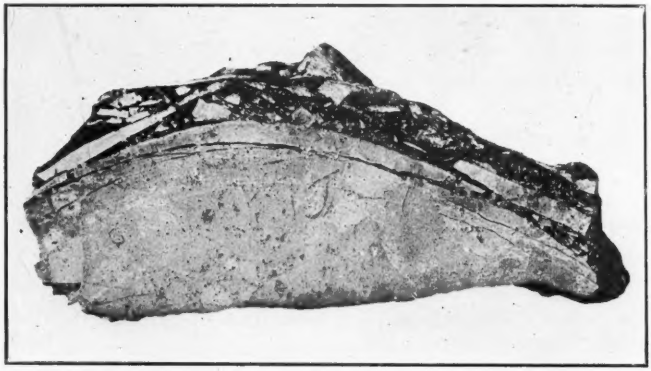

FIG. 46. Part of the shell of a bomb in the breccia ore.

the surface. Figure 46 shows a portion of the outer shell of one of these bombs in which the process of shelling off by the introduction of thin films of quartz and pyrite along the curved cracks is readily seen. On the polished face of the interior portion of the bomb an original breccia structure can still be faintly distinguished, and a few, but not all, of the darker spots on that face are minute crystals of pyrite. In immediate contact with the

outer surface of the bomb the cement is largely made up of quartz, enclosing comminuted fragments of country rock, while further away it contains an increasing amount of chalcopyrite and pyrite. Whether some of the chalcopyrite may not be due, like the bornite and chalcocite, to secondary concentration could not be definitely determined, but this was suggested by the apparent far greater proportion of this mineral in the ore of the upper levels rather than in a corresponding position on the tunnel level.

Distribution of Ore.—The manner of occurrence of the ore is as singular as its composition and structure. It is not a vein deposit, nor does it occur in what might be called a chimney or stock. From a first inspection of the drifts and stopes, shown on the mine maps, one might be led to think that in the interior of Pilares Mountain is a huge dome-shaped boss surrounded by a shell of ore a hundred feet or more in thickness. This appearance may perhaps be understood by an inspection of figure 47, which is a sketchy reproduction of the main drifts on the 400-foot level, in which the squares represent roughly the areas stoped in the southeastern part of the hill from which has come the greatest part of the ore mined up to this time. The stopes and drifts, both above and below this level, are singularly like it in form, varying mainly in their relative extent. They have not been represented, however, as they would unnecessarily complicate the drawing, nor have the workings in the ore bodies near the Y shaft, as they are too distant, but the relative position and direction of the two tunnels are indicated. (Figure 47.) Observations along the two tunnels, and in other drifts in the interior of the hill, show that, in point of fact, the ore is not confined to the outer shell, but that the whole mass of Pilares Mountain between the two shafts is more or less impregnated with ore, though not always of a quality that would pay to work under existing circumstances. The original deposition, as well as the secondary enrichment, which has rendered the ore rich enough to work, are both dependent on dynamic movements that have taken place along certain fracture planes. To illustrate this, these structural features, which have had to do with the unusual

concentration of ore in the southeastern part of the mine, have, in the sketch represented by figure 47, been emphasized by indicating their intersections with the mine workings on each level of the mine as far as they could be observed. They will be described somewhat in detail.

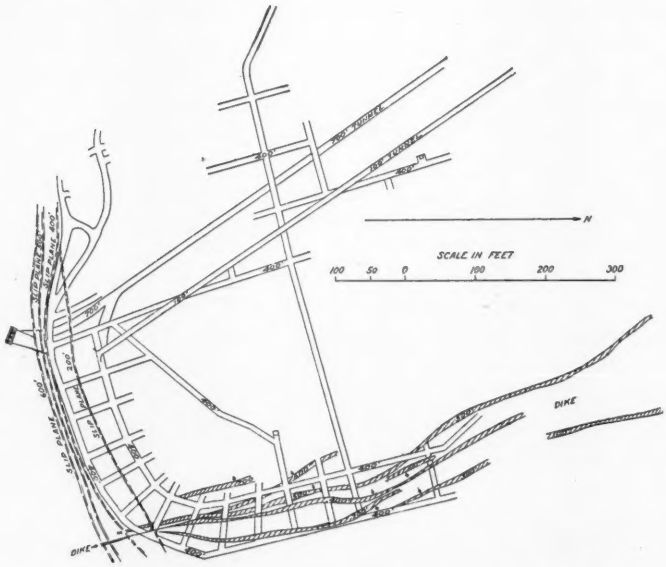

FIG. 47. Los Pilares Mine—projection of main drifts on 400-foot level, with intersections of dike and slip-plane.

The earlier of the two faults, which is designated on Figure 47 as the slip-plane, crosses the station on each level a short distance north of the main shaft and runs in a nearly east and west direction parallel to the main drifts of this part of the mine. It is a singularly clean, smooth plane of movement without clay selvage, sometimes made up of several closely-spaced planes. At one point 21 such planes were counted in a width of less than 2 feet. It stands nearly vertical, having a dip of about 70° to the south

and in strike shows a tendency (which is more marked on the upper levels) to bend northward at either extremity.

The passage from solid, practically barren monzonite, to mineralized breccia, as one crosses the slip plane on the successive levels, is remarkably sharp. Pyrite is first seen in thin, vertical seams on the inner planes of movement beyond which the whole mass is typical breccia. At first the cement is made up mostly of metallic sulphides, then of an increasing amount of quartz and groundup fragments of country, the sulphides decreasing in a general way with the distance from the fissure. At irregular intervals throughout the mass are found the barren bombs.

The second plane of movement is seen about 250 to 350 feet east of the shaft, where it crosses the slip plane nearly at right angles, its average strike being a little west of north. It is called by the miners "*Caliche*," and, as first seen, had the appearance of a thin, black clay selvage. Following it along the strike it proved to be a dike of very dark diabase that had been subjected to movement and intense compression, so that in places it is drawn out to a mere knife-edge seam and then enlarged to six or eight, and even fifteen, feet in thickness. In these thicker parts, which have a somewhat lenticular form, the original rock structure is readily distinguished in the interior, while the outer surfaces are changed to a plastic clay. In a general way it forms the eastern limit of the ore as far as present developments show, but in places typical breccia ore is found on the outer or eastern side of the dike—in one place over a hundred feet in length. As shown by the projections (figure 4) this dike has a wavy, curving direction, both in strike and dip. In its upper part it dips outward, or to the east, but changes in direction at the 300-foot level, and below the 700-foot level, as shown by drill cores, its dip shallows to 65° west.

That it is later than the slip plane is readily proved where their intersection is visible. The former ends abruptly on the face of the dike, but its continuation is traceable through the country rock on the other side, whereas the dike crosses the slip plane without break in its continuity. Rounded fragments of ore are

also found in the clay selvage, while the interior of the dike is free from any impregnation of sulphide, even microscopic.

This great mass of richer ore, whose exterior limit is defined by these two planes, and which, as shown by the maps, has a somewhat curving outline, is said to have been worked for a length of 1,300 feet along the arc of the so-called circle, whose chord is 800 feet across. The stopes of richer ore extend from a short distance below the 100-foot level down nearly to the 500-foot. Below this the ore is said to be falling off in grade, so that it can no longer be broken down in mass, as above. It is thus evidently to secondary enrichment that it owes its quality as pay ore. Above these limits, the copper is leached out; within them is the greatest concentration of the richer sulphides and, while they can still be observed in the lower levels of the mine, it is evident to the eye that they are in decreasing proportion. The actual amount of ore in the hill, aside from the question whether it can be mined under present conditions—that is, carries an average of 3 per cent. of copper—must, however, be something enormous.

Pilares Ore Body.—About 400 feet north of the main shaft is the Pilares ore body; so-called because it is directly under the outcrop of that name. It is newly opened and on the 400- and 500-foot levels only, and its relations to the fracturing were not so clearly seen, but a strong northeast fissure, 4 inches in width, was observed to run through it on the 500-foot level, and immediately under this, on the 700-foot, or tunnel level, is a strong vertical fault zone, with 5 or 6 feet of fault material. For a little distance on either side of this fault the rock is massive but soon passes into typical breccia again, in which here and there are patches of 3 per cent ore. It is significant that at the southern end of the drifts, on the 500-foot level, are a series of open cracks and holes, rounded out interiorly, and evidently old water courses. One of them, which traverses a part of the ore body, was seen to be filled with loose crystals of pyrite which had evidently been disintegrated by the passage of the waters.

On the main tunnel, a little beyond the Y shaft, or at about 3,000 feet from the portal, another diabase dike is cut, of rather

irregular form, and having a general north and south direction, which follows another ore body mainly developed by the upper workings of the Y shaft, which were not visited. In these upper levels the dike is said to thin to a mere clay seam, while the ore is found now on one side, now on the other, but does not extend far into the hill. On the tunnel level 60 feet beyond the dike is the contact between brecciated and somewhat mineralized monzonite, and the Paulina andesite, which is a vertical fault contact. In the other direction from the dike, or toward the center of the Pilares Mountain, the brecciated ore extends for a short distance and is succeeded by about 600 feet of massive rock, rather darker in color than the average monzonite, in which pyrite occurs only in narrow seams or veinlets. This rock is crossed by many northeast fracture planes of which there are two prominent ones having each 6 inches of soft, ground-up material. From beyond the last of these, or about 3,700 feet from the portal, to the main shaft, extends the typical light colored breccia which carries pyrite, mostly as cement to the breccia, but occasionally in irregular patches. In it are occasional masses of massive monzonite up to 100 feet through, generally bounded by movement planes, which are often rounded and resemble bombs on a large scale.

CONCLUSIONS.

Leaving out of consideration the question whether the acid Pilares rock is an intrusion in the Paulina andesite, or simply an area of silicification of the latter, the observations outlined above seemed to have defined with reasonable certainty three epochs in the geological history of these deposits:

1. An epoch of dynamic movement which produced the fault planes, of which the slip plane is a type, and resulted in a shattering of the greater part of the mass of Pilares Mountain, which was accompanied, or followed, by the introduction of silica and metallic sulphides that cemented the shattered fragments into a breccia.

2. An epoch of eruptive action during which the diabase dikes were introduced; and

3. A subsequent dynamic movement that opened new cracks through which the surface waters could enter.

The peculiar breccia that has become ore is not an eruptive breccia, produced by explosive vulcanism, nor is it a friction breccia consisting of broken and dragged-in fragments between the two parallel walls of a fault fissure, yet it has certain features of resemblance to either. It resembles the former in the uniform composition of fragments, in its great extent, and its want of regular, well-defined boundaries; for, while its limits on the plane of the tunnels and shafts are fairly well known, they are, apparently, not determined in directions more or less normal to this plane. It is quite possible, however, that the brecciated area may have something of the circular form that it is conceived to have by those who are working in it, for it is known that circular ore bodies, or so-called chimneys, often result from the mineralization of a shattered area, enclosed by three or four intersecting fault planes. It resembles a friction breccia, on the other hand, in that it has been produced by dynamic movements, and the ore fills the interstices between the fragments; but the shattering has taken place, not between the walls of the fissures, but at some distance outside of them, while the rock immediately adjoining the fault walls is generally massive or sheeted. Although the interdependence of the rock shattering and the faulting produced by the dynamic movements seems fairly well established, it is not easy to conceive why this peculiar form of brecciation was the result. It may be well to state that many more planes of movement than those mentioned above were observed, and that, doubtless, a great many more exist than were noted in such a hasty study, so that it may be assumed that every part of the brecciated mass is surrounded by fault planes. If we further assume that the movements along such fault planes communicated to the adjoining rock something in the nature of vibratory shocks, of an intensity probably proportional to the extent of the movements, and that such shocks were transmitted in waves, where there was no interference, as in the immediately adjoining rock, the transmitted movement might have no mechanical effect, or result only in some parallel sheeting. When, however, these waves were crossed by

waves of other fault movements in the vicinity, by interference there might result a violent shattering of the rock mass. If the general mass of the rock had already suffered decomposition by the introduction of heated solutions and gases along preexisting joint planes, the angular masses bound by such joints would have been decomposed in concentric zones, producing the observed tendency to flake off in curved shells when the shattering actually took place.

The introduction of the ore-bearing solution must have been subsequent to the shattering, but probably followed it very closely, since the ores were precipitated in the interstices rather than as the replacement of an already existing cement. While at greater depths these solutions may have ascended along the fissures, in the horizons now under observation it is evident that they had spread out more or less through the whole shattered area, though more concentrated along certain zones to which they found readier access.

The cause of the introduction of the diabase dikes was evidently a deep-seated one and possibly beyond the reach of present observation. It may be assumed that they followed cracks produced by some later movements, and, as shown above, they are parallel to some zones of mineralization and transverse to others.

The most important determination from an economic point of view is that of the location and extent of the channels produced by later movements which, by admitting surface waters, would have led to the secondary enrichment that has made the ores merchantable. Such a determination, especially in a relatively arid country where evidence of actually percolating moisture is not readily apparent, would require a more detailed and extended study than the present. Probably the strongly brecciated zones are still more or less permeable, but that there has been movement since the intrusion of the dikes is proved by the existence of old water channels cutting the ore bodies, and by the squeezed and drawn-out condition of the dikes themselves. Furthermore, the only considerable flow of water observed in the mine was found at the northernmost intersection of the dike by the 500-foot level; hence, it may be assumed that in the search for new ore bodies of

enriched ore, it would be advisable to follow the general course of the dikes in ground not yet explored.

The study of these deposits has proved especially interesting to the writer, because of a certain analogy between them and a new type of deposits which are proving of increasing economic importance. These are the bodies of disseminated cupriferous pyrite along shattered zones in porphyry that have been sufficiently enriched to admit of successful reduction by ore dressing and concentration, such as are being worked at Bingham, Utah, and Ely, Nevada. It is believed that the Los Pilares region is well worthy of a more complete and detailed geological study.

EXPERIMENTS ON THE SOLUTION, TRANSPORTATION AND DEPOSITION OF COPPER, SILVER AND GOLD.

H. N. Stokes.

INTRODUCTION.

The experiments described in this paper were made some three years ago in the laboratory of the U. S. Geological Survey. Owing to the writer's transfer to the Bureau of Standards and to another field of chemical work, the investigation had to be discontinued. As there seems to be no prospect of resuming it in the immediate future, and as numerous requests for the publication of the preliminary results have been made by geologists to whom they were privately communicated, it seems advisable to give them out in their present incomplete form. The writer can lay no claim to being a geologist and therefore, apart from a few suggestions, he has thought it best to leave to geologists the discussion of any possible bearing on the theory of ore deposition which they may possess. It need only be pointed out, by way of summary, that through the reversal of certain reactions by fall of temperature, solutions carrying ferric or cupric salts, after acting upon certain minerals at a somewhat elevated temperature, may, upon reaching cooler regions, deposit metallic copper, silver or gold, and that by a similar change of temperature, neutral or acid solutions carrying ferrous and cupric salts may yield hematite at one place and metallic copper at another.

SOLUTION AND DEPOSITION OF COPPER.

SOLUTION OF METALLIC COPPER BY HOT CUPRIC SULPHATE SOLUTION AND ITS REDEPOSITION ON COOLING.

Foerster and Seidel[1] showed that certain deviations from expected results in working with the copper voltameter were to

[1] *Zeit. Anorg. Chem.*, **14**, 118 (1897).

be explained by the solvent action of cupric sulphate solution on metallic copper, according to the equation

$$Cu + CuSO_4 = Cu_2SO_4.$$

They further demonstrated that the reaction is reversible. When metallic copper is in contact with cupric sulphate solution there is always a certain amount of cuprous sulphate formed, which is quite considerable even at a moderately elevated temperature. A solution saturated with cuprous sulphate in equilibrium with cupric sulphate readily deposits metallic copper on cooling. Richards, Collins and Heimrod[1] devised an apparatus with continuous circulation of cupric sulphate solution, which was heated in one portion of the circuit containing metallic copper, and cooled in another, where the greater part of the dissolved metal was redeposited. In this way considerable amounts of copper could be recrystallized. Abel[2] developed the theory of the reaction more fully.

The conclusion from these experiments which interests us most is that cuprous sulphate may exist in more concentrated form in conjunction with cupric sulphate at a high, than at a low temperature; that a solution saturated with it will deposit metallic copper on cooling and that therefore a solution in which cupric sulphate has been partly reduced to cuprous sulphate, may, if carried to another and cooler region, deposit metallic copper.

A simple apparatus, with continuous circulation, was devised to illustrate the behavior of hot ascending solutions, in the lower and warmer part of which the reaction between the mineral or metal and the solution was brought about, while in the upper, cooler portion the reaction was reversed, with deposition of metal. A glass tube of about 4 mm. caliber, bent at an angle of about 120° and having limbs of about 12 cm. long, contained the solution and the substance to be acted on, the latter being in the lower, vertical limb. The lower limb was inserted in a narrow gas pipe closed at the bottom and immersed in a bath of Wood's

[1] *Zeit. physikal. Chem.*, **32**, 324 (1900).
[2] *Zeit. Anorg. Chem.*, **26**, 381 (1901).

fusible alloy. The alloy was contained in a piece of 2½″ gas pipe, 6″ long, closed at top and bottom by caps, the narrow pipe being screwed into the top cap. The object of the narrow pipe was to prevent scattering of the alloy in case of explosion. Four such pipes were inserted into the cap, admitting of three simultaneous experiments, the fourth pipe carrying a thermometer, while in the center of the cap was a hole admitting an ordinary Reichert's temperature regulator, by which the bath could be kept fairly closely at 200°, the temperature employed in all the experiments. The upper inclined limb of the tube was water jacketed and cooled by a continuous current of water. The tube was charged by introducing the substance and then nearly filling with the solution, displacing the air by carbon dioxide and sealing off at the upper end. This left a small gas bubble, which was gradually dissolved by the hot solution and liberated on heating in the lower end, where it remained. To prevent this surrounding the substance to be acted on, the latter was carried on a small glass support. Under these conditions the convection was so slow that the lower limb was practically the temperature of the bath, and when the tube was charged with metallic copper and acidified cupric sulphate solution, the metal was rapidly dissolved and deposited in crystals in the upper limb.

FERROUS SULPHATE AND CUPRIC SULPHATE.

That ferrous compounds are agents in reducing copper from its salts has long been suspected by geologists.[1] H. C. Biddle[2] has shown experimentally that metallic copper may be formed when an alkaline carbonate in excess acts on a solution of cupric and ferrous sulphates. Up to the time of my experiments, however, the reduction of cupric salts to metallic copper by ferrous salts in neutral or acid solution had not been effected. In fact, it was very well known that such solutions do not deposit copper or give other sign of the reduction of the cupric compound. I

[1] Pumpelly, *Am. Journ. Sci.* (3), **2**, 188, 243, 374 (1871). Geol. Survey of Michigan, Vol. I., pt. 2, p. 19 (1873). R. D. Irving, U. S. Geol. Survey, monograph V., p. 419 (1881–3).

[2] *Am. Chem. Journ.*, **26**, 377 (1901); *Journ. Geology*, **9**, 430 (1901).

have shown elsewhere[1] that when these sulphates are heated together in solution at 200° there is a deposition of ferric oxide with cuprous oxide and possibly metallic copper. The reaction between the sulphate may be expressed by the reversible equation

$$2CuSO_4 + 2FeSO_4 \rightleftarrows Cu_2SO_4 + Fe_2(SO_4)_3.$$

Ferric sulphate undergoes partial hydrolysis to ferric hydrate and sulphuric acid, especially at higher temperatures, at which also the ferric hydrate may be deposited as hematite, while cuprous sulphate, if sufficiently concentrated, deposits metallic copper on cooling as shown above. We should therefore expect a deposition of hematite in the hotter, and of metallic copper in the cooler region. This was clearly verified with the apparatus just described. The tube was filled with a solution containing in 40 c.c., 2 grams crystallized ferrous sulphate free from ferric salt and 1.8 grams crystallized cupric sulphate, these being the proportions required by the above equation. After heating the lower limb for an hour at 200°, a crystalline deposit of copper was observed in the upper limb, while after 20 hours there was an abundant crystallization of copper in the upper limb, and the lower limb was lined with a black crust, showing a blood red color by transmitted light. This was seen under the microscope to consist of granules which were blood red by transmitted light, and which gave a red powder, being thus sufficiently characterized as hematite. No other substances were deposited. The reaction can obviously continue until the hematite is in equilibrium with the liberated sulphuric acid at the temperature employed.

PYRITE AND CUPRIC SULPHATE.

I have shown elsewhere[2] that pyrite, heated with a solution of cupric sulphate, gives rise to sulphides of copper, ferrous and ferric salts, and in the case of cupric chloride, to cuprous chloride also. We should expect under the conditions of the previous experiment to get a deposit of metallic copper in the upper limb and of hematite in the lower limb. Powdered pyrite was heated

[1] U. S. Geol. Survey Bulletin 186, p. 44.
[2] U. S. Geol. Survey Bulletin 186, p. 42, 44.

with a slightly acidified 10 per cent. cupric sulphate solution for 18 hours at 200°. Crystalline copper was deposited, as expected, in the upper limb, while the contents of the lower limb were much darker in color and in part had the color of bornite. Hematite was not looked for, but may have been present. The cuprous sulphate which gave rise to the deposition of copper may have come not only from the reducing action of the ferrous salt, but also of the pyrite upon the cupric sulphate, as shown by the experiment with cupric chloride just referred to, and as expressed by the equations

$$FeS_2 + 14CuSO_4 + 8H_2O = 7Cu_2SO_4 + FeSO_4 + 8H_2SO_4$$
$$7Cu_2SO_4 = 7Cu + 7CuSO_4.$$

That there is a partial oxidation of the sulphur of the pyrite to sulphuric acid cannot be doubted.

CHALCOCITE AND COVELLITE WITH CUPRIC SULPHATE.

Experiments with chalcocite and cupric sulphate show that the former is readily decomposed with deposition of metallic copper in the cold region. Covellite, however, was very resistant, no deposit of copper being observed after 2 days' continuous heating at 200–230°, using saturated cupric sulphate solution. The reaction in the case of chalcocite may be thus expressed:

$$Cu_2S + CuSO_4 = CuS + Cu_2SO_4 \downarrow$$
$$Cu + CuSO_4$$

SIDERITE AND CUPRIC SULPHATE.

Ten per cent. neutral cupric sulphate solution was heated at 200° with coarsely powdered siderite in the lower limb. Metallic copper was deposited in the upper limb, and also in the lower; there was also a formation of hematite and malachite in the lower limb.

HORNBLENDE AND CUPRIC SULPHATE.

In order to try the action of a ferrous silicate, a powdered hornblende rich in ferrous iron was heated with 10 per cent. cupric sulphate solution containing about 2 per cent. free sulphuric

acid. After heating about 12 hours, considerable metallic copper was deposited in the upper limb, while the lower hot limb contained hematite.

SOLUTION AND DEPOSITION OF SILVER BY HOT ASCENDING SOLUTIONS.

SILVER AND CUPRIC SULPHATE.

In this experiment silver powder was heated for 15 hours at 200° with a solution containing 5 per cent. crystallized cupric sulphate and 2 per cent. free sulphuric acid. The silver was completely dissolved and deposited in crystallized form in the upper limb. The reaction is obviously:

$$2Ag + 2CuSO_4 \rightleftarrows Cu_2SO_4 + Ag_2SO_4,$$

the reaction reversing at the lower temperature. As no metallic copper was thrown out it is clear that the cuprous sulphate reduces the silver salt before it begins to deposit copper.

SILVER AND FERRIC SULPHATE.

It is well known that ferric sulphate solution dissolves silver, the more, the hotter the solution, while on the contrary ferrous sulphate reduces silver salts. This reversible reaction, which is represented by the equation

$$2Ag + Fe_2(SO_4)_3 \rightleftarrows Ag_2SO_4 + 2FeSO_4$$

was illustrated by the following experiment. Silver foil was heated in the lower limb of the tube with 7.5 c.c. of a solution of ferric alum containing .75 grams iron per liter, and 2.5 c.c. 30 per cent. sulphuric acid to prevent hydrolysis. A copious deposit of crystals of silver formed in the upper cool limb.

SOLUTION AND DEPOSITION OF GOLD BY HOT ASCENDING SOLUTION.

GOLD AND CUPRIC SALTS.

Gold leaf was heated at 200° with a solution containing 85 grams crystallized cupric chloride and 133 c.c. 20 per cent. hydrochloric acid in a liter. After 16 hours, the gold was found to

be completely deposited in crystalline form in the upper limb. The reaction is presumably

$$Au + 3CuCl_2 \rightleftarrows AuCl_3 + 3CuCl$$

the cuprous chloride reducing the gold solution as the temperature falls. Cupric sulphate solution was without action. Addition of a chloride to the cupric sulphate would doubtless lead to the above result.

GOLD AND FERRIC SALTS.

It is a favorite theory that ferric sulphate is a solvent for gold. While this cannot be absolutely denied, the following experiments show that under the unusually favorable conditions involved in the method employed, no solvent action could be detected, unless a chloride is present at the same time.

GOLD AND FERRIC SULPHATE.

Gold leaf was heated with a solution of ferric alum containing 10 grams iron and 15 grams free sulphuric acid per liter. After 52 hours continuous heating at 200° not a trace of gold had been deposited in the upper limb, and the gold leaf was unchanged.

The experiment was then repeated with the addition of .01 gram sodium chloride. After 40 hours heating, a small amount of gold had been deposited in the cold limb. The ferric chloride formed from the sodium chloride is obviously the active agent in this case. This was further confirmed by the following experiment.

GOLD AND FERRIC CHLORIDE.

Gold leaf was heated in a mixture of 2 parts 20 per cent. solution of crystallized ferric chloride and 1 part 20 per cent. hydrochloric acid at 200°. The ferric salt was free from nitric acid. After 27 hours, the gold was found to be completely deposited as crystals in the upper limb. The reaction may be expressed by the equation

$$Au + 3FeCl_3 \rightleftarrows AuCl_3 + 3FeCl_2.$$

BUREAU OF STANDARDS,
WASHINGTON, D. C.

SKETCH OF THE GEOLOGY AND ORE DEPOSITS OF THE COCHISE MINING DISTRICT, COCHISE COUNTY, ARIZONA.

L. O. KELLOGG.

INTRODUCTION.

The Cochise Mining District lies in the southeastern part of Arizona and in the southwestern part of Cochise County. It centers about the town of Johnson while the most accessible railroad point is Cochise on the Southern Pacific, reached by a wagon road, nine miles long, with easy grades. Other mining camps are in the vicinity, Bisbee and Tombstone lying to the south while Pearce and Gleason nearby are of some importance.

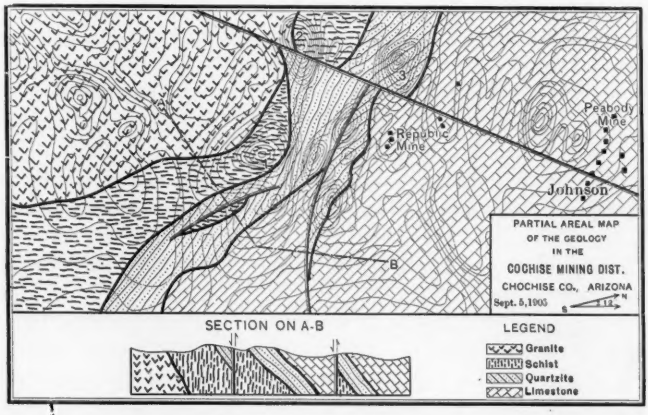

FIG. 4c. Partial areal map of the geology in the Cochise Mining District, Cochise County, Arizona.

The district extends along the southeastern flank of the Little Dragoons, a small range of mountains with a generally north and south trend, and rising abruptly from the surrounding plain.

The topography of the copper-bearing belt is not rugged though hilly. The rather prominent hills, called 1, 2, and 3, rise in its southern portion. In rougher country to the south wolframite is found.

The copper minerals and wolframite constitute the ores of the district, though the latter is mined only on a small scale. Not much copper was being produced in the fall of 1905, but considerable development was going on, especially at the Republic Mine. In times past the St. Georges and the Mammoth have produced some of the metal while the Peabody yielded, according to report, about a million dollars worth of ore.

GEOLOGY.

The areal geology and a typical section with exaggerated dips in the formations are shown on the accompanying map. The granite core is overlain by a schist to the north on which lie unconformably quartzite and limestone with northerly dip. Quartz veins both mineralized and barren cut all the formations.

The sedimentaries are the north flank of an anticline or dome, caused by the intrusion of the granite, the uplifting effect of which was responsible for the formation of the mountains.

Considerable faulting occurred during the mountain building process or subsequently. While not presenting themselves strikingly in the field the faults explain the distribution of the different formations as observed. They probably influenced ore deposition to a large extent.

No evidence of faulting subsequent to the formation of the ore bodies was noted.

The granite is a light-colored rock of normal granitic composition, but varying considerably in texture. In some places it is grano-porphyritic but its composition is essentially the same in its various phases and aside from its texture it seems to be of only one variety. It is to the intrusion of this igneous mass that the folding and faulting of the district, the contact phenomena and the mineralization must be ascribed.

The mica schist lies next to the granite everywhere except on the flank of hill No. 2. It shows little effect of metamorphism

from contact with the granite but is evidently the result of some regional, metamorphic influence exerted upon an impure sandstone. It is composed almost wholly of mica and quartz, often containing large pebbles of the latter. It has a foliation with vertical dip and north and south strike which may or may not correspond with its original bedding.

Uncomformably on the schist lies a sedimentary series with a quartzite at the bottom. The quartzite outcrop is about 1,200 feet wide when not faulted, representing a thickness of about 900 feet. It strikes northwest and dips 40 degrees to the east. It is impure but very hard and usually shows at the bottom a basal conglomerate.

The limestone, which lies conformably on the quartzite so far as can be seen, has about the same dip and strike. It is of considerable thickness, 3,000 feet being shown within the limits of the map, but probably represents in itself several formations. It is usually semi-crystalline, sometimes soft and impure, both white and blue, often cherty. It is in the limestone that by far the greater part of the copper is found.

The limestone in its lower part shows contact metamorphism in the form of a typical garnet zone, composed of a brown garnet with other metamorphic minerals. Associated with these are bodies of copper and zinc sulphides.

A few unimportant igneous dikes are found, all much altered. All the formations are traversed by quartz veins which in the granite may carry wolframite and in the other formations are usually barren, though a few carry copper.

The granite corresponds to the granite-porphyry of Bisbee, which has produced the mineralization of that district by its intrusion. The schist can be correlated with the Pinal schist of Bisbee and of Globe, which is Pre-Cambrian. The presence of the unconformity between the schist and the sedimentaries is a striking instance of similarity in the three districts.

The basal conglomerate and the quartzite can be correlated with the similar formation at Bisbee which is put down as Cambrian.

The limestone cannot be divided into horizons because of the lack of paleontological evidence. A few fossils indicate that it includes the Carboniferous, and it is probably older than this in part, but does not include any Mesozoic strata.

ORE DEPOSITS.

WOLFRAMITE ORES.

The ore deposits of the district include two types: (1) Wolframite ores; and (2) copper ores—the latter type being that which gives to the district its commercial importance.

The wolframite deposits are not for the greater part included in the mapped area, most of them being found in a series of granite knobs about a mile south of the limits of the map.

The mineral occurs in place in numerous quartz veins in the granite, which by erosion have furnished placer deposits of some extent. The veins are composed of a fine white translucent quartz, called "bull-quartz," varying in thickness from a few inches up to two feet, usually dipping at a steep angle, very regular in thickness with sharply defined walls. As they have not been much mined their longitudinal extent and the distribution of the useful mineral could not be determined.

It cannot be stated whether the quartz veins in all the different formations are of the same age or not. Those in the granite are differentiated by the fact that they alone carry wolframite. The most reasonable interpretation of them is that they are late emanations of the granite intrusion which filled crevices in the partly consolidated mass. They would thus represent a very acid pegmatite. Those not bearing wolframite in the schist and the sedimentaries may be of a similar nature or they may be fissure veins filled by a later deposition.

The wolframite itself occurs in fragments up to a pound in weight disseminated through the quartz. While comparatively rich, the extreme narrowness of the veins, their probably limited longitudinal extent and the hardness of the rock makes them difficult to work so that most of the tungsten production is from placer workings in the stream beds and arroyos leading

out of the granite knobs. The high specific gravity of the wolframite makes its separation very easy.

COPPER ORES.

General Character.—The copper deposits are by far the most important in the district, and it is in them that future development must take place, the tungsten deposits being comparatively limited in extent and incapable of being systematically mined. The most extensive deposits of copper are replacements in the limestone. Some of the quartz veins in all the formations may carry a little chalcocite but they are relatively unimportant.

The map, Fig. 5, covers the greater part of the copper bearing district, outcrops and stains being more or less common through all of the limestone as far north as the Peabody, thence east to the beginning of the wash, and west nearly to the higher peaks.

According to other observers these deposits follow zones of fracture and occur in faulted areas, omitting the quartz veins from consideration, but from the writer's observation they seem more often to follow bedding planes in the limestone. In the case of the St. Georges, Mammoth and Republic mines, the inclined shafts follow down the dip of the limestone in ore. In the Peabody, it is stated, there is not the same regularity.

It is evident that the mineral-bearing solutions have penetrated the rocks along openings of some kind, metasomatically replacing the limestone thus laid open to attack and extending into the wall rock on either side. The resulting deposits are consequently approximately tabular in shape, without definite walls and of very indefinite and variable thickness, gradually changing outward from the center to undecomposed limestone and proportionally decreasing in richness.

The deepest workings outside of the Peabody extend 300 feet on the dip of the limestone, at an angle of about 40 degrees. The depth of the Peabody workings is unknown to the writer but is probably in excess of this. At no place has the permanent water level been reached and its depth is problematical, but probably it is great as is usually the case in this section of Arizona.

Nature of the Ores.—Most of the copper minerals are represented in the ores. Chalcopyrite, bornite, malachite and chalcocite are most abundant. Chrysocolla, azurite and cuprite are also found. Tenorite and native copper are mentioned by other observers but were not seen by the writer. The sulphides are relatively abundant, considering the fact that the workings are still shallow and are in limestone, conditions most favorable for the production of cuprite and the carbonates.

In some cases there is considerable zinc blende in association with the copper minerals. This is especially true in the case of the garnet zones where blende rather predominates.

No chalcocite was found in association with the most typical ores but it occurs in veins of quartz, usually alone. Pyrite was not seen at all except as microscopic inclusions in the blende and as small crystals sparsely disseminated in some parts of the country rock.

The commonest gangue minerals are garnet, quartz and calcite. Epidote is not uncommon. Quartz is often observed of two generations in the same specimen, the later being in the form of small veins cutting the other minerals.

The relations of the minerals in the ore were studied by means of polished surfaces with reflected light under a metallographic microscope. In all of the specimens alteration was in progress, usually in the chalcopyrite which was invariably present.

Where blende and chalcopyrite constituted the ore the blende usually seemed to be older as it often showed definite crystal boundaries which the chalcopyrite never did. Whenever present, the blende was apt to show as inclusions sections of what seemed to be small pyrite crystals. Along the contact of the blende and the chalcopyrite or of gangue, chiefly garnet, and chalcopyrite a dark bluish green decomposition product could be observed, of indeterminable composition. In some cases the gangue was quartz apparently included in the sulphides and older than them but also present as small veins cutting all the minerals and evidently the result of secondary silicification.

When bornite was present, as was often the case, it seemed to be younger than the chalcopyrite but while it cannot be said that

it was not an alteration product of the chalcopyrite, it seemed not to be so as the boundaries between the two minerals were always distinct. Both chalcopyrite and bornite in such a case show alteration to a blue green product like malachite or chrysocolla in color but apparently metallic. This occurs in cracks in both sulphides and also along their contacts. When adjacent to bornite it appears to be two different minerals, a dark and a light. It may in its darker phase, which is also shown in the chalcopyrite, represent some enriched sulphide, richer than bornite, and in its lighter phase represent a step toward this. It might be a splitting up into chalcocite or covellite and iron oxide but in that case it would be reasonable to expect the chalcopyrite to follow the same process. The bornite itself shows pink and it is the alternation of this with the blue decomposition product that gives the typical iridescent effect to peacock ore, suggesting that most bornite is in process of alteration and consequently very uncertain in composition.

Massive chalcopyrite was found altering to oxidized products. The process seemed to begin along cracks and contacts and extend into the sulphide splitting it up into detached areas and in its final stage destroying its composition and appearance altogether. The decomposed material was soft and dark brown with a sharply outlined, slate-colored band against the fresh sulphide. It effervesced with acid showing the presence of a little carbonate. The decomposition process seems to include a differentiation of oxides, a copper oxide forming next to the sulphide and a band of limonite segregating inside that, the carbonate being innermost.

The general conclusions brought out are that blende may be present in ore in small quantities invisible to the naked eye; that what appears to be pure blende to the unaided eye may show inclusions of pyrite under the microscope; that alteration of sulphides begins along fissures through the minerals as well as on their boundaries and gradually eats its way into the interior; that alteration into oxides may be accompanied as well by a differentiation of the oxides and thus render their separation by leaching and consequent enrichment of the copper ores more easy;

the fact that bornite may be an original mineral; and that it and chalcopyrite associated may pass through similar stages of decomposition to some richer product.

Origin of the Ores.—In their general nature the deposits resemble very closely those usually characterized as contact deposits containing many of the minerals generally ascribed to the effect of contact metamorphism. They are distinguished, however, by the fact that there is no igneous mass of any size visibly in contact with the limestone. The few dikes met with are too insignificant to account for the garnet zone and the mineralization and the possibility of an overlying sheet totally removed by erosion seems hardly reasonable. It is necessary therefore to fall back on the intrusive granite for an explanation. The distance on the surface separating the metamorphosed and mineralized areas from the granite is no greater than has been observed in similar cases elsewhere, but the schist and the quartzite would be unsatisfactory media for transmitting contact effects. The presence of faults, cutting the strike, other than the one shown on the map may have been overlooked. If present they might have served to carry the mineralized solutions across to the limestone where they were precipitated. Rather more plausible is the hypothesis that the granite cuts the limestone in depth and the contact phenomena observed on the surface are merely the extension upward of more profound changes below.

It is probable that the intrusion of the granite brought with it the materials necessary to form the sulphides and part of the gangue in the ore, which were deposited by reaction with the lime carbonate, a process facilitated by the condition of the rock where the solution entered, a large surface of contact being afforded both by bedding planes and fissured fault zones.

A possible explanation of the deposits is that the heat of the intrusion stimulated the circulation of vadose waters, which collected from the surrounding rocks the elements of the ores and deposited them in cracks and cavities, the solutions not being derived from the intrusion. In this case the deposits would not be of the contact variety.

Lacking analyses the possibility of this manner of formation for the ore bodies cannot be denied but it seems unlikely that the bulk of foreign material in the garnet zones, for instance, could have been furnished by the country limestone. It is assumed that the formation of the garnet zones and of the copper deposits was simultaneous. Indeed there is no sharp line to be drawn between them. The garnet zone is ore geologically speaking and garnet is a common gangue in most of the ores.

The process of enrichment which took place after deposition was undoubtedly due to the action of surface waters leaching and reprecipitating the sulphides.

In conclusion the writer takes pleasure in expressing his acknowledgments to Professor Kemp, Dr. Berkey, and Dr. Campbell, of Columbia University, for advice and assistance in the preparation of this paper.

ORIGIN AND OCCURRENCE OF CERTAIN IRON ORES OF NORTHEASTERN KENTUCKY.[1]

W. C. PHALEN.

GENERAL STATEMENT.

The Hanging Rock region of Kentucky comprises the extreme northeastern corner of the State, and includes Boyd, Greenup, and Carter counties. The iron ores of this region are chiefly earthy carbonates, spathic ores, or siderites, but on the outcrop and extending in on the beds to variable distances, depending largely on the porous or non-porous character of the roof, they have been altered to the hydrous ferric oxide, limonite. Most of the ores occur in the Pottsville and Allegheny formations, the two lowest members of the Pennsylvanian series as developed in this part of the State. Locally, however, ore horizons occur in the Conemaugh formation, as for instance, near the tops of the hills east of Louisa, Kentucky, on the West Virginia side of the Big Sandy River. These ores have been classified by P. N. Moore[2] as follows:

1. Limestone ore.
2. Block ore.
3. Kidney ore.

To this list may be added a fourth class of black band ore. These may be described briefly as follows: (1) Limestone ores are those which occur upon, or very near, the top of a limestone stratum. Very frequently they occupy a broader field than the limestone, but in such cases if the ore occurs near the stratigraphic position of the limestone, the term is still applied. In eastern Kentucky, these ores occur at two horizons; the lower associated with the Mississippian; the higher with the Ferriferous[3] lime-

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] Ky. Geol. Surv., Rept. on the Eastern Coal Field, Vol. C, p. 89.

[3] Used in the sense that E. B. Andrews uses the term in the reports of the Ohio Geological Survey.

stone. (2 and 3) Block ore and kidney ore are so called from their physical appearance. The former cleaves into more or less square or rectangular prisms when raised from its bed; while the latter derives its name from its peculiar kidney shapes. Both varieties occur as unaltered carbonates, or earthy siderites, except where oxidized to limonite. (4) The term black band is applied to beds of carbonate of iron with more or less bituminous and earthy matter associated. A notable example of this ore occurs on the property of the Torchlight Coal Company on Levisa Fork in Lawrence County. The deposit lies about 15 feet below coal No. 4[1] and varies from eight to twelve feet thick, consisting of layers of black or carbonaceous siderite from one to three inches thick, alternating with thin layers of bituminous shale. The ore, which carries 55.12 per cent. iron carbonate, compares favorably with the Scotch black band ores.

Of these various types only the ore associated with the Ferriferous limestone has now any importance as a source of iron. This ore occurs not only in Kentucky, but in eastern Ohio, and over a large part of the bituminous coal field of Pennsylvania. It is generally conceded that the limestone associated with the ore is an original deposit strictly conformable with the associated strata, but this unanimity of opinion does not appear to have obtained regarding the origin of the unweathered ore.

Various hypotheses have been advocated to account for this ore. One of the earliest of these is that of H. D. Rogers[2] who regarded the original form as a sesquioxide which had subsequently been reduced through the agency of the associated carbonaceous material of the Coal Measures. This view is regarded now as wholly untenable, though it was not without its adherents. Still another hypothesis accounts the ore as pseudomorphous after limestone; it holds that the overlying ferruginous shales and clays have given up their iron content, which has been carried down and deposited upon the limestone, which pari passu

[1] The numbers are used according to the usage of Crandall. Crandall's report on the Eastern Coal Field of Kentucky.

[2] Lesley's "Iron Manufacturers' Guide," p. 635.

has been dissolved and carried away. This derivation of ore by percolation through and precipitation from overlying ferruginous shales has at least been suggested, if not specifically stated, by Lesley[1] as a mode of origin for the ore overlying the Ferriferous limestone in Lawrence County, Pennsylvania. It was accepted by Moore[2] as the most probable hypothesis to account in most cases for the limestone ores of Greenup, Carter, and Boyd counties, Ky., viz., the region under discussion. This hypothesis has also been advocated by Shaler[3] and Kimball[4] to explain the origin of certain limestone ores. There are certain factors, however, in the problem in Kentucky to which the writer would call attention, and it is the object of this paper in part to present another hypothesis and to give reasons for the same to account for these limestone ores as observed in Kentucky. This hypothesis, namely, that of original deposition, was early advocated by Newberry and will be amplified in another paragraph (see page 667).

CHEMICAL GEOLOGY.

Siderite forms the end member of a series of isomorphous carbonates among which are the following: Ankerite $CaCO_3 \cdot (MgFe)CO_3$; breunnerite $(MgFe)CO_3$; mesitite $(2MgCO_3 \cdot FeCO_3)$, and pistomesite $(MgCO_3 \cdot FeCO_3)$. It seems to be agreed among chemical geologists that the original source of the iron and other bases in these minerals is in the igneous rocks, and that carbon dioxide behaves towards ferrous iron silicate much as it does toward calcium silicate, that is, it decomposes it, forming the corresponding carbonate. In an excess of carbon dioxide both iron and calcium carbonates are soluble, but the conditions for the maintenance of ferrous carbonate as such must be altogether exceptional. Its precipitation, like that of calcium carbonate, may take place when the carbon dioxide holding it in

[1] Second Geological Survey of Pennsylvania, Rept. Q_2, 1877, preface, p. 25.

[2] Moore, P. N., Report on the Iron Ores of Greenup, Carter, and Boyd counties, Kentucky, Ky. Geol. Survey. Report on the Eastern Coal Field, Vol. C, pp. 85 and 94.

[3] Geol. Survey of Kentucky, Vol. 2, p. 163.

[4] *American Geologist*, Vol. 8, p. 358.

solution is removed by its escape into the air, or by its removal by plant cells, but with access of air it is readily converted into the higher state of oxidation. The presence of limestone undoubtedly has an important influence in certain cases on its precipitation, and many of our deposits of carbonate of iron are replacements of limestone by this substance, but even when calcium carbonate is present with the iron carbonate it is not always certain that the latter has really replaced the former, for iron carbonate may be precipitated with calcium carbonate in the form of the mineral ankerite, and in combination with other bases, as indicated in the series of isomorphous minerals given above. Stelzner[1] cites an interesting case in this connection. He refers to the crystalline spathic ores, of the Erzgebirge, which are interlaminated with layers of true limestone. If such masses are really metasomatic replacements of the limestone, as has been commonly held to be the case, it is inconceivable, according to him, why the remaining limestone was not also replaced. It is also difficult to explain as pseudomorphous replacements the formation of iron carbonate in hot springs where no limestone is present, and in bogs and marshes where limestone is also absent. These two carbonates being isomorphous it were as plausible to assume the necessity for ferrous or some other isomorphous carbonate to initiate the precipitation of our chemically deposited limestones as to argue for the necessity of the existence of calcium carbonate to cause the precipitation of iron carbonate. The two substances behave similarly. They may be precipitated together in the same molecule, as in the mineral ankerite, and either may precipitate without the other.

THE LIMESTONE ORES.

Discussion.—It is a fact well known to students of coal measure geology, that the fireclays (underclays) associated with the coal beds, owing to their impermeable nature, render the overlying coals water-bearing horizons, and are themselves marked by springs along their outcrops. In the region under discussion the ores associated with both the Mississippian and

[1] "Die Erzlagerstätten," Vol. I, p. 198.

the Ferriferous limestone are almost immediately overlain by important beds of fireclay. It may be mentioned that there is usually a small streak of coal or black shale (bone) associated with these fireclay deposits. The fireclay overlying the Mississippian limestone approaches the iron ore lying on this bed to within a foot or two, as in the Olive Hill region, and that over the ore of the Ferriferous limestone to within nine or ten feet at Willard, while in the Ashland district the ore and limestone are in the clay horizon itself.[1]

SECTION AT OLIVE HILL, CARTER COUNTY, KENTUCKY.

	Feet.	Inches.
Coal		2 to 6
No. 3 fireclay	1 to 9	
Flint clay	1 to 9	
"Semi-hard" clay	1 to 5	
"Pink-eye" clay	3	
Blue shale		18 to 20
Iron ore		4 to 8
Massive Mississippian limestone.		

At Amanda Furnace where the following section was measured by Moore, it will be observed that the fireclay rests directly on the ore and is capped by a small seam of coal.

SECTION AT THE HORIZON OF THE FERRIFEROUS LIMESTONE BACK OF AMANDA FURNACE.[2]

	Feet.	Inches.
Soil	4	—
Clay shale	6	—
Coal	0	4
No. 2 fireclay	3	—
Pottery clay	4	—
No. 1 fireclay	3	—
Limestone ore	—	8
Top of the Ferriferous limestone.		

Were the iron ore derived from the overlying shales and fireclay, it seems reasonable to suppose that at least some iron carbonate would still be present in the fireclay. The clays are generally very pure, and this, on a priori grounds, may be taken as

[1] See section at Olive Hill on this page and the section near Ashland, p. 668.
[2] *Op. cit.*, p. 141.

an indication that their ferruginous content has been removed, but then most of our Pennsylvania underclays are comparatively free from iron whether they occur near an ore bed or not. Instead of allowing the passage of water, carrying iron ore in solution, it is the writer's opinion that a bed of clay, such as occurs in the Olive Hill region, which sometimes runs as high as fifteen feet thick, would act as a barrier preventing the descent of iron-bearing solutions and that there would be at least a tendency to deposit carbonate ore (the only soluble variety) at the top of this horizon. So far as known, the tops of these clay beds are not ore horizons in eastern Kentucky. The clay banks visited near Willard and at Olive Hill appear to be exceptionally dry, and give no evidence of percolating waters at the present time.

ANALYSES OF FLINT CLAY.

	1.	2.	3.
Silica	50.95	48.56	46.75
Alumina	39.49	37.471	38.17
Iron oxide	——	Trace	Trace
Calcium oxide	——	.112	0.17
Magnesium oxide	0.28	Trace	Trace
Phosphoric acid	——	2.55	——
Potash	0.30	.289	Trace
Soda		.283	
Water	9.18	13.03[1]	14.03
	100.20	100.000	99.12

No. 1. Sciotoville fireclay, N. W. Lord, analyst. Ohio Geological Survey, Vol. VII., p. 58.

No. 2. Sample from upper part of bed from ridge between Grassy and Three Prong creeks, Carter County, Kentucky. Sample collected by P. N. Moore; Robert Peter, analyst; Kentucky Geological Survey, Report on Eastern Coal Field, Vol. C, p. 10.

No. 3. Sample from near Olive Hill, Carter County; analysis furnished by Ashland Fire Brick Company.

But the subject of the permeability or impermeability of clay with respect to solutions of ferrous carbonate has not been determined. It is a difficult matter to handle the ferrous salt in the laboratory owing to the ease and rapidity with which it is converted to the higher state of oxidation. Granting, then, that

[1] Expelled at red heat.

the clays are permeable to some extent, it is but natural to expect to find more or less of the iron carbonate disseminated through them or in nodular form in the same, on the supposition of descending solutions, for, as will appear from the evidence cited under the head of chemical geology, it is not essential to the precipitation of ferrous carbonate that calcium carbonate be present.

The eastern Kentucky clays are generally pure and the Olive Hill clay is exceptionally so. Even where iron is present no trace of carbon dioxide (CO_2) is indicated in the analyses, thus proving the complete absence of ferrous and calcium carbonates. Some analyses of the flint clays are as follows:

An analysis showing the small content of iron and the absence of carbon dioxide in the clay at the horizon of the Ferriferous limestone is also given:

Silica	40.14
Alumina	43.72
Iron oxide	1.98
Lime, Magnesia	1.60
Water	12.56
	100.00

Upper stratum of clay at Ferriferous limestone horizon, Ashland, Kentucky; Dr. Robert Peter, analyst. Analysis furnished by the Ashland Fire Brick Company.

If the ferrous carbonate comes from the overlying beds, and if its precipitation does not depend upon the presence of limestone, as seems to be the case from the evidence cited, then the ore should be found disseminated through the beds below its original source and would not occur at the perfectly definite horizons, as is the case in eastern Kentucky.

The interval between the clays and limestone is so small (never over a few feet) that it is difficult to conceive of the shales carrying enough ferruginous material to produce the iron ore found on the underlying beds. Moreover, for reasons already stated, it may be difficult for circulating waters to reach such material except along or near the outcrop of the deposits.

There is a certain phase of the limestone ore deposits which deserves mention in this place; that is the irregularity in shape of these deposits. They sometimes vary rapidly in thickness, but again, as near Boone furnace, in Carter County, are quite regular. This seemingly erratic behavior is difficult to explain on the hypothesis of ordinary deposition. It is perhaps due in part to the action of laterally circulating waters which tend to segregate the ferruginous molecules in much the same way as our lenticular limestone nodules form in clay.

Conclusion.—As a result of these observations, it is believed that another hypothesis is admissible to account for some of the iron carbonate deposits of Kentucky where these are associated with limestone. It is believed that they are original and were deposited after the limestone. If the iron carbonate has undergone resolution and re-deposition, the movement is believed to have been horizontal for the most part, but not chiefly vertical; if the latter movement has taken place it has been necessarily within very narrow limits. The presence of ironstones near the top of the limestone, but not resting on it, is taken as an indication that the iron carbonate continued to form after the limestone, and independently of the latter, having segregated to its present position through lateral movement.

This hypothesis of conformable deposition has been advocated by Newberry to account for the calcium carbonate ore of the Coal Measures. He regards this ore as having formed in lakes like the Clinton ores. In his own words:[1]

"The calcareous ore usually caps the limestone and seems to have been produced during the interval when the water basin was becoming shallow and contracted so that the iron carbonate, which was held in solution by a large body of carbonated water, was precipitated as the quantity of water was diminished."

It is quite possible that in instances the deposition of limestone and carbonate ore proceed contemporaneously, possibly in part as the mineral ankerite. The microscopic study necessary to determine the identity of different mineral species has never

[1] *The School of Mines Quarterly*, Vol. 2, p. 14.

been performed, so far as known, but it is hoped that at some future time the writer may have opportunity to do this work. Lesley has stated that the limestone and iron carbonate, as observed by him at Hartman's ore banks in West Virginia, is a double carbonate of lime and iron.[1] In such instances careful microscopic study is necessary to be sure that the combination may not be due to replacement.

The change from siderite to limonite is so obvious as to need no comment here. The reaction, according to Stelzner, is as follows: $4FeCO_3 + 3H_2O + O_2 = Fe_4O_3(OH)_6 + 4CO_2$. The limonite is found wholly on the outcrop and extends for variable distances into the hill, depending on the porous or non-porous character of the roof.

Present Development.—Only the limestone ore of the four classes cited has any importance at the present time as a commercial product. The ore used is obtained solely from the Ferriferous limestone horizon, which has recently been worked on a small scale in the western part of Ashland, Kentucky, in connection with the important fireclay from this horizon. The ore and limestone occur between the clay strata, and the following section obtained from the William T. Johnston bank west of Ashland indicates the relationships.

SECTION OF FIRECLAY AT THE WILLIAM T. JOHNSTON BANK WEST OF ASHLAND, KENTUCKY.

	Feet.	Inches.
Dark fireclay	4	
Iron ore, averaging		6
Limestone, occasionally reaching a thickness of	4	
Black shale, not always present		2
Light drab clay	2	

The limestone is used by the Ashland Iron and Mining Company, and when a sufficient quantity of the ore is gotten together, it also is utilized by the same concern. No ore has been shipped recently. The ore occurs in the form of limonite and is usually dense, dark red and close grained.

[1] Report Q, Second Pennsylvania Survey, Preface, page 16.

Summary.—The limestone ores of the Carboniferous system of eastern Kentucky have heretofore been regarded as replacements of limestone by ferruginous solutions, derived from overlying sediments. As a result of his last season's work the writer found that these ores are frequently overlain, either immediately or within a few feet, by important beds of fireclay ranging from four to fifteen feet in thickness. It is believed that such fireclay beds are practically impervious and would not allow ferruginous solutions to percolate through them, but that if such beds were partially permeable, then some of the iron carbonate passing through them would still be found in them for the reason that iron carbonate may precipitate without necessarily replacing calcium carbonate, which, as happens to be the case, occurs a few feet below the fireclay beds. The fact that these overlying fireclays are free from iron and carbon dioxide leads to the conclusion that the iron ore was deposited before the clay, and hence is original. Finally, that the irregularities sometimes exhibited by the iron ore beds may be due to subsequent segregation brought about by laterally moving solutions.

THE LOWER IRON ORES INCLUDING THE CLINTON ORE.

To the west of the Hanging Rock region, and in the vicinity of Licking River, the formations below the Coal Measures are brought above drainage. In this region iron ore is found at not less than four distinct geological horizons, of which that resting on the Mississippian limestone is the youngest. This ore, so far as known, is not worked at the present time, but formerly had considerable importance, and to it was due the reputation of the Red River region in the iron market of the country. Near the base of the Waverly shale, clay ironstone and kidneys occur in numerous beds, varying from four inches to a foot or less in thickness. This ore is a hard, blue carbonate, a type that was little used by the old charcoal furnaces, and in this particular instance, so far as known, never utilized, though containing a sufficient iron content to give it value. The Preston ore, the next lower in the geologic series, has been described as the Clin-

ton ore, but is now known to occupy a higher stratigraphic position, occurring in Devonian rocks. These old Preston ore banks have considerable historic as well as geologic and economic interest, for the first furnace built in Kentucky, and perhaps west of the Alleghanies, was erected on Slate Creek, Bath County, in 1791, to work the ore from this horizon. It was in operation making charcoal iron for forty-seven years, going out of blast in 1838. The ore, when it attains its maximum development, is from seven to fifteen feet thick, and is chiefly limonite, though it is occasionally a carbonate in part. Ore at this horizon has been observed to the southwest in Montgomery, Clark, Boyle, Lincoln, and Casey counties, and Mr. E. M. Kindle, of the United States Geological Survey, has observed ore at this same horizon in Ohio, some fifty miles to the northwest. Thus the linear extent of this belt of occasional ore deposits is about one hundred and fifty miles. Analyses of this ore by Dr. Robert Peter[1] show a content of iron oxide varying from 52 to 80 per cent. The lowest as well as the most important ore at the present time in this district is the Clinton oolite. This ore, in Kentucky, except along the Pine Mountain fault, is confined to Montgomery, Fleming, and Bath counties, and only in the latter does it assume economic importance. It underlies several thousand acres of land, chiefly to the east and southeast of Owensville, the county seat of Bath County, nearly all of which might be mined with a small amount of stripping. At the time of Linney's report (1886) but a few tons of the ore had been mined, and several small furnace tests had been made. According to the report it mined easily, and gave a fairly satisfactory quality of soft fluid foundry iron, which was somewhat cold short. At the present time the ore deposits are being worked by the Rose Run Iron Company, a few miles west of Salt Lick, and the ore is shipped raw to Ashland, Kentucky, Ironton, Ohio, and Big Stone Gap, Virginia. The ore bed appears to lie perfectly flat and under a shallow cover. It has been found inexpedient to work it at a greater depth below the surface than ten feet. Drifting has never been attempted, the overlying ma-

[1] Kentucky Geological Survey, old series, Vol. 4. p. 62.

terial being removed by means of a steam shovel, and the ore blown out with dynamite and transferred from the mine breast to the tipple by mules and cars. Plows are frequently pressed into service to loosen the overlying material.

There are two varieties of ore: first, the weathered; and second, the hard, non-weathered material. The former resembles limonite somewhat, and is found only on the outcrop. The unweathered ore runs as high as five feet thick, though it averages about two and one half feet. No limestone is mixed with it, there being enough of this substance present to obviate the necessity of adding it during the smelting, though the ore is by no means a limestone ore in the sense that this term is used in the higher horizons; neither is any kidney ore known to occur in the associated shales. Lying directly over the main ore horizon is usually found three inches of ore quite high in sulphur. This material formerly was separated and roasted, a treatment never necessary in the case of the main body. At the present time, however, the roaster lies idle, since there is an insufficient quantity of the sulphurous ore to keep it in continuous operation. Sections obtained at two different points are as follows:

SECTION 1.

	Feet.	Inches.
Green shale, with two or three inches of impure limestone at or near the surface of the ground....	5 to 6	
Limestone		6 to 8
Green shale		6
Iron ore	2½	

SECTION 2.[1]

	Feet.
Yellow surface clay	2
Thin-bedded sandstone and shale	5
Blue clay shale	6
Iron ore	4

During the last thirteen years, the period in which the deposits have been worked, fifteen acres of ore have been removed. The yield per acre has been estimated by Mr. C. H. Graves, the superintendent, as about 3,000 tons for each foot of thickness.

[1] Section measured by Mr. E. M. Kindle.

Since a fair average thickness seems to be about two and one half feet, the average yield per acre is about 7,500 tons, making the total yield to date about 112,500 tons. Several thousand acres of workable ore undoubtedly still exist, most of which must be worked by different methods from those at present employed. With the increase in the demand for lower grade ores, such as the Clinton, much of this ore will eventually be obtained by drifting after the shallow deposits are exhausted. The quality of the ore is represented by the following analyses by Dr. Peter from samples obtained by W. N. Linney.[1]

Iron peroxide	47.630	51.430	58.570
Alumina	5.468	5.132	3.720
Lime carbonate	16.560	13.080	15.160
Magnesium carbonate	9.974	9.444	4.528
Phosphoric acid	1.202	1.138	1.010
Silica	7.160	7.800	6.960
Moisture expelled at 212°	1.143	0.693	1.607
Undetermined	10.863	11.283	8.445
	100.000	100.000	100.000

The following figures were kindly furnished by Mr. C. H. Graves, the superintendent of the Rose Run Iron Company:

	Per cent.		Per cent.
Metallic iron	34.28	to	38.60
Alumina	3.54	"	6.80
Lime	8.86	"	11.21
Magnesia	4.08	"	5.84
Manganese oxide	.10	"	.22
Silica	4.19	"	8.73
Sulphur	00	"	.01
Phosphorus	.43	"	.61

The unweathered ore, which is brownish in hue, is generally oolitic in appearance; in some instances, however, this is not marked. It is also quite fossiliferous and streaked with bands of calcareous matter of a grayish hue (Fig. 49). In these lighter streaks, shown well in the illustration, oolites of ore are frequently seen. When the limestone bands grow thicker, the number of oolites grows less and finally they disappear. These round and reniform particles do not show plainly lines of growth in the iron oxide, even when examined in thin sections in re-

[1] Report on the Geology of Bath and Fleming counties, p. 19.

flected light. When gently crushed, no concentric shells are seen. Their interiors are, however, always more porous and of a yellowish hue, and contrast strongly with the firm and denser peripheries. In thin sections the nuclei appear almost without exception to be calcareous and are usually the tests of ostracoda and bryozoa. Frequently between the outer dense layer and the

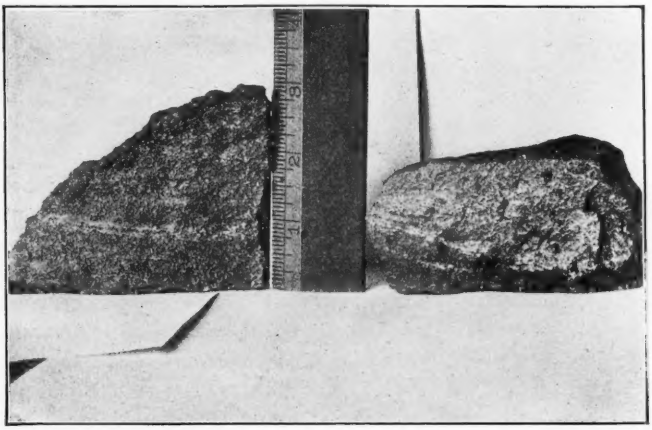

FIG. 49. Clinton ore from Bath County, Ky., showing limestone bands. (Photo by F. W. de Wolfe.)

inner porous portion occurs a concentric layer of calcite. The delicate network of the cells is often entirely replaced by iron oxide. In the calcareous layers shown in the illustration the oolites occur completely isolated, but in no wise different from those not thus set apart. The replacement of the cells must have occurred before the rock became thoroughly lithified by the calcareous cement, for ferruginous solutions could hardly exercise a selective action and precipitate about calcareous tests rather than in the abundant calcareous matrix surrounding such tests. It thus seems that they have reached their present positions in an oxidized form and hence are original in their nature.[1]

[1] See C. H. Smythe, Jr., *Am. Jour. Sci.*, third series, Vol. XLIII., p. 487; *Zeit f. Prakt. Geol.*, 1894, p. 304.

THE LIGNITE COALS OF NORTH DAKOTA.

FRANK ALONZO WILDER.

Practically all of the western half of North Dakota lies within the great northwestern Laramie lignite area. The eastern border of the lignite may be indicated by a diagonal, extending from Steele, a station of the Northern Pacific Railway about fifty miles east of Bismarck, northward till it crosses the Canadian border at a point fifty miles east of Portal, which is the last station in the United States on the "Soo" Railroad. South from Steele, the line should be drawn to the mouth of the Cannon Ball River; the longer fork of this river will serve as the southern boundary for the lignite area to the west end of the Standing Rock Indian Reservation. From this point, the line must be projected southward into South Dakota. To the north and west, the lignite extends without a break into Canada and Montana. One important outlier of the Laramie is found to the east of this line. This is the so-called Turtle Mountains, a rolling plateau, some forty miles long and thirty miles wide, about three hundred feet above the surrounding country. The lignite that is known to exist in northeastern Bottineau and north Rolette counties is confined to this plateau.

Wherever the Laramie occurs in North Dakota, lignite in commercial quantities may be expected: the Laramie increases in vertical extent toward the western part of the State, and with it the lignite beds increase in number and thickness. The railroad well at Madora, on the Little Missouri River, penetrated the Laramie clays for 941 feet without going through them. Seventeen lignite beds were encountered, varying in thickness from a few inches to twenty-four feet, the total collection aggregating sixty feet. A similar record was given by the well at Dickinson.

The greater part of the North Dakota lignite area lies outside the drift-covered region, and outcrops are abundant. West of the Missouri River they are so frequent that the advertising of

the real estate man, "Cheap lands and free coal!" is hardly an exaggeration. Ranchmen generally take their own coal from some natural exposure, asking leave from no one. Magnificent outcrops of lignite occur along the Missouri and its tributaries. They are particularly abundant along the Little Missouri. Here the dark lignite bands, between beds of brilliantly-colored clays, may be traced for miles. The section at Medora is typical.

17.	Clay	20
16.	Argillaceous sandstone	1
15.	Clay	20
14.	Lignite with much selenite	8
13.	Clay	40
12.	Lignite, good quality	3
11.	Clay	20
10.	Sandstone	5
9.	Clay	40
8.	Lignite, good quality	6
7.	Clay	8
6.	Calcareous shale	1
5.	Clay	17
4.	Lignite, good quality	8
3.	Clay	10
2.	Lignite	3
1.	Clay	27
	Water level.	

The heaviest bed of lignite that has been reported up to the present time was found in southwestern North Dakota on Sand Creek, a tributary of the Little Missouri, in Township 135, Range 101, Section 31. In a cut bank at this point there appeared:

Clay	5 Feet.
Lignite	3 Feet.
Clay	2 Feet.
Lignite	40 Feet.

The forty-foot lignite bed was unbroken by clay seams or bands of nodules and the whole bed appeared to be made up of a good quality of lignite. Near the base of Sentinel Butte, a twenty-five-foot lignite bed outcrops, which is mined for local purposes by stripping. At Spanish Point, on the Missouri River, a little below the town of Williston, four lignite beds are exposed in a single section,—three feet, six feet, fifteen feet, and eight feet

thick, respectively. At the town of Lehigh, on the Northern Pacific, a fifteen-foot bed is mined extensively. The Washburn mine, by far the largest mine in the state, situated near the town of Wilton, about eighty miles above Bismarck, takes coal from a bed that averages eight feet in thickness.

The writer has not hesitated to refer all the workable lignite beds of North Dakota to the Laramie, though the upper portion of these beds was regarded as distinct, and called the Fort Union, by Lesquereux. There seem to be no satisfactory stratigraphic or paleontological grounds for this differentiation. The plants which Lesquereux regarded as typical Fort Union forms were found in the lower beds at a number of localities. The recent studies of Dr. A. G. Leonard confirm this opinion.

The North Dakota lignites are generally brown in color and very woody. Entire tree trunks are not uncommon, flattened by pressure till they resemble great slabs. The leaves and cones of Sequoia are abundant in the associated clays. The dark colored lignites are generally composed of the finer forms of vegetable matter. On account of their water content, the lignites check badly or slack on exposure to the air. Their fuel value, if proper appliances for burning fine coal are used, is probably increased, rather than diminished, by this process of slacking.

The lignites show a certain amount of deterioration at points of natural outcrop. Weathering has altered the coal for a few feet, but the quality improves rapidly from the face of the outcrop. The lignite generally appears fresh at the end of a drift only six or eight feet long. In a few instances the upper portion of the bed is slacked, and does not improve in quality away from the outcrop. The effect is the same as that which would have been produced, had the upper portion of the bed been exposed to the air while the lower portion was preserved beneath the water. A fifteen-foot bed, which outcrops a few miles west of Dickinson and may be seen from the car window on the Northern Pacific R. R., will serve as an illustration. Here the upper half of the bed consists of soft, crumbling lignite slack, containing 22 per cent. of ash. Occasionally an entire bed is made up of this slack coal, though such beds are usually thin. In prospecting,

it is sometimes difficult to determine whether the slack, exposed at the surface, is due to mere deterioration at the outcrop of a good bed, or whether the whole bed is inferior. In general, it may be said that if the quality does not materially improve on drifting in six or eight feet, the probabilities are that the entire bed is soft. In this weathered coal, whether it occurs at the outcrop of a good bed, or composes a slack bed, there are numerous fragments of jet, exceedingly hard and lustrous, and burning like pitch.

When considered as fuel, the lignites deserve a better place than that which is commonly assigned them. A real injustice has been done these coals, high in volatile hydrocarbons, by judging them on the basis of their fixed carbon alone. There was a time when anthracite coal was regarded as worthless, because it could not be made to burn satisfactorily with the simple appliances that were used for bituminous coal. In the same way, the lignites have been condemned, because satisfactory results were not obtained from them in the ordinary stoves and furnaces.

Twenty-five analyses, made by the Geological Survey of North Dakota, show that the moisture in the lignite averages 33 per cent. Analyses of two car samples, made at the coal testing plant at St. Louis, show 35 per cent. and 36 per cent. of moisture. Analyses of twenty-six samples, taken during the year 1900 by the Geological Survey of North Dakota, gave, after drying, carbon 52 per cent., volatile matter 40 per cent. and ash 8 per cent. The two car samples analyzed at the St. Louis testing plant gave, in addition to the moisture, volatile matter about 29 per cent., fixed carbon 27 per cent., ash 7 per cent., sulphur 1 per cent. The lignite generally loses about one-half of its moisture by air drying.

With the introduction of the under-feed stoker, which permits the use of the air dried, and hence the fine lignite, and which renders available for fuel purposes most of the volatile hydrocarbons, the rank of lignite as a fuel producer has changed considerably. It is being brought even more to the front by the introduction of producer gas.

It shows fair efficiency, however, when burned green under ordinary boilers and on common grates. A trial test of lignite coal from the Washburn mine at Wilton, made by the Fargo, Edison Co., at Fargo, on January 9, 1901, gave the following results:

Boilers used—two 72–16 tubular, one 200-horse-power Heine water tube.	
Total heating surface	4,823 sq. ft.
Total grate surface	88 sq. ft.
Average steam pressure	83 lbs.
Average temperature of feed water	140°
Total weight of coal fired	26,400 lbs.
Total weight of water pumped into boilers and apparently evaporated	97,500 lbs.
Water evaporated per lb. of coal from average pressure and temperature	3.7 lbs.
Equivalent evaporation from and at 212°	4.1 lbs.
Coal burned per sq. ft. of grate per hour	25 lbs.
Per cent. of moisture in coal	30%
Per cent. of refuse in coal	3½%

Duration of test, twelve hours. Time of test, from 4 P. M. to 4 A. M., January 9, 1901.

The boiler tests of North Dakota lignite, made at the fuel testing plant at St. Louis, gave the following results:

Duration of trial	9.85 hrs.
Total coal consumed	10,680 lbs.
Horsepower developed in boiler	108
Dry coal burned per sq. ft. of grate surface per hour	17.15 lbs.
Equivalent evaporation from and at 212° F. per lb. dry coal	5.4 lbs.
Dry coal per indicated horsepower hour	5.24
Dry coal electric horsepower per hour	6.47

The earlier successful attempts made in North Dakota to utilize lignite under boilers, involved the use of forced draft, obtained by a fan. A number of plants, however, which use from 100 to 300 horsepower, find that they obtain satisfactory results from lignite with ordinary draft.

For the entire region, west of the Red River Valley and extending nearly to the mountains in Montana where the lignite comes in competition with bituminous coal, the lignite, when used in the ordinary manner, is the economical fuel. In the Red River Valley, it competes on an even basis with the bitumi-

nous coal brought by cheap boat freight to Duluth and thence by rail.

When used as a source of producer gas, the lignite can readily extend the territory which it controls till its eastern border is beyond the Red River Valley. The following tables, taken from the Preliminary Report of the coal testing plant at St. Louis, show the efficiency of lignite when converted into producer gas.

COAL, NORTH DAKOTA No. 2; PRODUCER-GAS TEST No. 10.

(Coal from the mine of the Cedar Coulee Coal Company, near Williston, North Dakota; tested November 14, 15, 1904.)

Duration of test	30	hrs.
Total coal consumed in producer	13,800	lbs.
Moisture in coal	39.56	%
Dry coal consumed in producer	8,340	lbs.
Refuse from dry coal	10.53	%
Total refuse from coal	878	lbs.
Total combustible consumed in producer	7,462	lbs.

COAL CONSUMED, POUNDS PER HOUR.

Coal consumed in producer	460
Dry coal consumed in producer	278
Combustible consumed in producer	249
Equivalent coal used by producer plant	510
Equivalent dry coal used by producer plant	308
Equivalent combustible used by producer plant	275.8

BRITISH THERMAL UNITS.

Per pound of coal as fired	6,802
Per pound of dry coal	11,255
Per pound of combustible	12,600
Per cubic foot of standard gas	188.5
From standard gas per pound dry coal burned in producer	7,830

GAS PRODUCED, CUBIC FEET (REDUCED TO STANDARD).

From standard gas per hour per brake horsepower	13,770
Total	346,400
Per hour	11,550
Per pound coal consumed in producer	25.15
Per pound dry coal consumed in producer	41.53
Per pound combustible consumed in producer	46.42
Per pound equivalent coal used by producer plant	22.68
Per pound equivalent dry coal used by producer plant	37.5
Per pound equivalent combustible used by producer plant	41.88

HORSEPOWER DEVELOPED.

Average electrical horsepower available for outside purposes	125.1
Average electrical horsepower developed at switch board	134.2
Average brake horsepower available for outside purposes	147.3
Average brake horsepower developed at engine	158

COAL CONSUMED IN PRODUCER, POUNDS PER HORSEPOWER PER HOUR.

	Coal as Fired.	Dry Coal.	Combustible.
Per electrical horsepower available for outside purposes	3.67	2.22	1.99
Per electrical horsepower developed at switch board	3.42	2.07	1.86
Per brake horsepower available for outside purposes	3.13	1.89	1.69
Per brake horsepower developed at engine	2.91	1.76	1.58
Equivalent pounds used by producer plant per electrical horsepower available for outside purposes	4.07	2.46	2.20
Equivalent pounds used by producer plant per electrical horsepower developed at switch board	3.80	2.29	2.05
Equivalent pounds used by producer plant per brake horsepower available for outside purposes	3.47	2.09	1.88
Equivalent pounds used by producer plant per brake horsepower developed at engine	3.23	1.95	1.74

AVERAGE COMPOSITION OF COAL AND GAS.

Coal.	Per Cent.	Gas by Volume.	Per Cent.
Moisture	39.56	Carbon dioxide	8.69
Volatile matter	27.78	Oxygen	.23
Fixed Carbon	26.30	Carbon monoxide	20.90
Ash	6.36	Hydrogen	14.33
Sulphur	.93	Methane	4.85
		Nitrogen	51.02
			100.02

The report indicates that the lignite proved to be an excellent gas producer fuel, and had but one drawback; this being its tendency to clinker. It yielded a yellow tar in small quantities. The behavior of the coal in the producer was, in general, very satisfactory.

The briquetting tests conducted at the fuel testing plant were interesting, and demonstrated that the Dakota lignites can be treated as successfully as the German brown coals.

Lignite is being used in most of the North Dakota brick yards, though it requires a little experience to handle it successfully in

the kilns. It will figure largely in connection with the irrigation enterprises in that state. The first of the large pumping stations which will lift water from the Missouri river to the fertile river flats is now in definite form, and bids for its construction are called for. At this pumping station and probably at all others, both public and private, lignite coal will supply the required energy.

Campbell's suggestion, made in an earlier number of this magazine, that the nature of the lignites is in part to be accounted for by the fact that they are covered by impervious clay strata which are sufficient to prevent the escape of volatile matter and hence keep down the percentage of fixed carbon, seems appropriate.

AN ONTARIO LEAD DEPOSIT.

J. Volney Lewis.

LOCATION.

The deposit described below is a galena-calcite vein in siliceous schist in central Hastings County, Ontario, Canada. It is in lot A, sixth concession of Madoc, and lies along the northern border of the township, two miles northeast of Bannockburn on the Central Ontario Railway, and about thirty-five miles in a direct line a little west of north from Belleville. It is the property of the Ontario Mining and Smelting Company and was formerly known as the Hollandia mine.

GEOLOGY.

The rocks of the immediate vicinity have been mapped by the Provincial Bureau of Mines as "crystalline limestone and calc schist together with conglomerate." This heterogeneous group forms an irregular triangular area some twenty miles on a side, which is much intersected and nearly surrounded by "dioritic rocks." Both of these have been intruded by large bosses and numerous dikes of granite, and the whole is overlapped to the southward by the Birdseye and Black River limestone. (See small-scale map, Fig. 50.)[1] The widespread and varied mineralization of the region may be realized from the fact that it contains nearly a dozen mines, representing deposits of arsenic, pyrites, gold, lead, and iron. These lie chiefly in the townships of Madoc and Marmora.

COUNTRY ROCK.

The rock in the vicinity of the mine is a highly siliceous phyllite, or fine grained quartz-schist, of dark gray color. Lamination is highly developed in the direction N. 40° E., with a quite uniform dip of about 75° to the northwest.

[1] The outlines of these formations have been generalized from the map accompanying Professor W. G. Miller's Report on the Gold Belt of Eastern Ontario, Eleventh Report of the Ontario Bureau of Mines, 1902.

To the unaided eye the mineral constituents of this rock are indistinguishable, with the exception of occasional small grains and stringers of marcasite (and possibly pyrite) in the immediate vicinity of the vein walls. Under the microscope it is found to consist chiefly of fine grained granulitic quartz with minute lamellæ of muscovite and biotite in alternate laminæ, the muscovite-bearing layers being much the

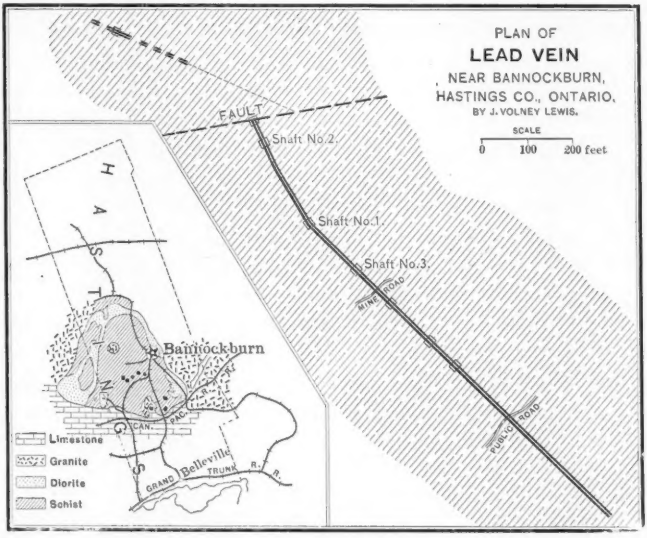

FIG. 50. Plan of lead vein near Bannockburn, Hastings County, Ontario. (By J. Volney Lewis.)

thicker. All of the minerals are much flattened in the plane of schistosity, the micas most notably so. Between the laminæ of the phyllite the cross-section shows minute scattering lenses of granular calcite. In the plane of schistosity these appear as circular areas 2 to 3 mm. in diameter, which are easily seen in thin section without the microscope.

Originally the rock must have been an exceedingly fine grained, argillaceous and slightly calcareous sandstone.

VEINS.

There are occasional quartz veins, but these are usually small and irregular and vary but little from the direction of schistosity. So far as observed they carry no other mineral than quartz.

The lead ore occurs in a vein of very different character. It occupies a clear-cut fissure with well-defined walls, cutting almost directly across the lamination of the country rock, as shown in Fig. 50. Its direction is N. 50° W., with a slight curve about shaft No. 1, and it dips 75 to 80° (hade 10 to 15°) to the southwest. The fissure is traceable for a distance of 1,100 feet, from near the border of a small swampy area at the southeast to where it is cut off by a fault forty-nine feet northwest of shaft No. 3. Beyond this the vein has not been satisfactorily identified. A galena-bearing vein exposed in a pit 400 feet to the northwest may be the same, but its direction is different, as shown in the figure, and its continuation has not been traced. For 500 feet south of the fault the vein has been opened in the mine workings and prospect pits and the thickness varies chiefly between two feet and seven feet. There is no selvage and the vein adheres firmly to the walls. Occasionally masses of the wall-rock are included in the vein, and rarely the fissure is largely replaced by a zone of such rock traversed by numerous small fissures.

VEIN MINERALS.

The ore is galena in masses ranging from minute grains to more than a foot in diameter. The larger masses are coarsely crystalline and have a prominent cubic cleavage. The gangue is white to rose-colored calcite in compact granular and coarser cleavable masses. In the walls and near them, in both the vein and the country rock, marcasite occurs in small crystals, cockscomb groups, incrustations, and in stalactitic forms in small vugs. In thin seams with the galena, siderite also occurs near the walls, besides occasional grains of sphalerite, pyrrhotite, and pyrite. A soft, greenish yellow, waxy hydrocarbon (paraffin or ozocerite) is also found in small particles imbedded in the vein.

The vein is essentially a galena-calcite deposit and the proportion of these two minerals varies greatly. In rock-filled portions

of the vein, or in those parts where the main fissure subdivides into numerous subordinate cracks, the galena content sometimes drops below one per cent. In the typical unobstructed fissure, however, the galena constitutes from 5 to 15 per cent. of the vein in the narrower parts, and from 20 to 40 per cent. of the whole in the wider parts. The regular manner in which this galena content varies with the width of the fissure in portions of the vein from which representative samples were assayed is strikingly shown in the diagram, Fig. 51.

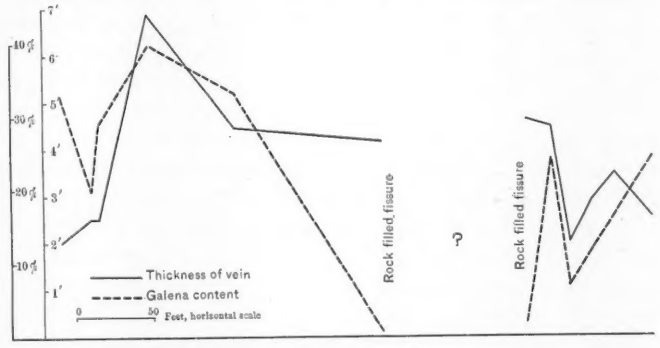

FIG. 51. Diagram illustrating relations of galena content to width of vein.

Glacial erosion has removed the oxidized parts of the vein, along with the weathered country rock; hence the minerals are often fresh quite to the surface. Alteration of the galena has subsequently given rise to some carbonate (cerussite) to a depth of about ten feet in places. There is also occasional evidence of slight leaching out of the calcite by percolating waters.

ORIGIN OF THE ORE.

In regard to the age and origin of the ore but little that is definite can be said in the present state of knowledge of the geology. The schists, diorites, and granites being overlapped to the south by the Birdseye and Black River limestones, are doubtless properly regarded as of pre-Cambrian age. An immense

period of, as yet, undeciphered geological history, however, is bound up in their formation and subsequent changes. Their elevation, deformation, and metamorphism, with at least two periods of igneous intrusion, were followed by extensive weathering and erosion before they were depressed to receive the Cambro-Silurian sediments.

The fault by which the vein is cut off to the northwest shows that fissures in other directions were formed either simultaneously or subsequently to the vein-fissure. On the other hand, the absence of shearing or other evidence of movement within the vein itself shows that the rocks have suffered little deformation since it was formed. The vein is unquestionably subsequent to the metamorphism of the sediments and to the schistosity across which it cuts. One naturally regards the intrusion of the surrounding belts of dioritic rocks and the later bosses and dikes of granite as an accompaniment of the various stages of deformation and metamorphism. The fissure may naturally be regarded as one of the last results of these waning activities and the vein-filling as the product of circulating waters in the crystalline sediments at some depth below the surface. Doubtless the rocks were still heated above the normal surface temperatures of the region, and there may well have been a residuum of volcanic heat.

The conditions that may be considered to have a more or less direct bearing on the question of origin of the ore may be enumerated as follows: (1) The association of galena, calcite, marcasite, and sphalerite, and the great predominance of the first two; (2) the remarkably regular variation of the galena content with the width of the fissure in typical portions of the vein, being greatest in those portions that allowed freest movement and easiest access of infiltrating waters from the walls; (3) the absence of quartz and silicates from the vein; (4) the practical absence of gold and silver, although the surrounding region contains numerous auriferous veins; (5) the absence of mineralization even in the most fissured zones of the wall-rock, and in portions of the wall-rock inclosed in the fissure; (6) the absence of known igneous rocks from the immediate vicinity of the vein.

Professor Miller[1] suggests that the auriferous quartz-arsenopyrite veins of this district were formed by magmatic waters from the cooling granitic intrusions; and in view of their relations, this seems highly probable. The characters enumerated above, however, emphasize the shary contrast between this lead vein and the prevailing type of gold-bearing vein of the neighboring mines; and strongly suggest that both the minerals and the waters by which they were deposited were derived from the adjoining sediments.

[1] *Loc. cit.*

THE GENESIS OF THERMAL WATERS AND THEIR CONNECTION WITH VOLCANISM.

ARMAND GAUTIER.[1]

The greater number of geologists believe that the water of hot or cold mineral springs originally percolated downward from the surface and after leaching various materials from the rocks was impelled upward through fissures by gravity or gaseous pressure. In other words, it is meteoric water. Prior to the prevalence of this view, however, Élie de Beaumont had suggested that metalliferous veins, volcanic ejecta and mineral springs all have a common origin. A third view has been presented by Suess, who maintains that from the central nucleus of the globe issue hydrogen, hydrocarbons and vapors of sulphur which are oxidized near the surface, partly by free oxygen and partly by oxygen already combined in the rocks, into water and carbonic and sulphurous acids. The present studies afford results not fully accordant with any of these hypotheses. It is believed that thermal springs, at least all those of high and constant temperature, are maintained principally by a kind of distillation of the deeper-seated rocks; that their mineral contents are derived especially from those magmatic regions where the igneous rocks begin to solidify and result from reactions that are also the cause of eruptive phenomena. An attempt will be made (1) to show that the genesis of volcanic eruptions can be compared to that of thermal waters and (2) to explain the mechanism through which the waters are mineralized or eruptions take place.

Geological observations in all parts of the world show that thermal waters are usually related to ancient or modern volcanoes and that they issue from fissures of the same character as those occupied by metalliferous veins or igneous dikes.[2] Hot

[1] "La genèse des eaux thermales et ses rapports avec le volcanisme." Par M. Armand Gautier. *Annales des Mines*, 6 ser., vol. 9, 1906, pp. 316–370. Freely translated and condensed by F. L. Ransome.

[2] Many examples, illustrative of this as well as of other points, are given in the original paper but are necessarily omitted from this abstract. F. L. R.

springs are, in fact, diminutive or attenuated phases of volcanic eruptions. Volcanoes themselves are abundant sources of hot water and no eruptions take place that are not accompanied by a copious discharge of water vapor. Fouqué has calculated that Etna, in 1865, furnished at least 11,000 cubic meters of water in twenty-four hours. The paroxysms lasted two hundred days but steam rose from the crater for a much longer period.

Although Daubrée in 1861 established the fact that water can penetrate rocks by capillarity against a pressure of some atmospheres, this experiment does not suffice to explain the access of meteoric water or sea water to the deep-seated regions where lavas originate. The temperature at which these lavas issue cannot be less than 1100° C. and andesite and many other igneous rocks do not melt much below 1200° or 1300° C. In accordance with the law of increase of temperature with depth, these rocks must have come from a region at least 35,000 or 40,000 meters below the surface.[1] At these temperatures such a column of lava would afford a pressure of 8,000 atmospheres at its base. Penetration by capillarity against such pressure seems impossible. It might be urged that the water erupted from a volcano is caught up by the lava during its ascent through rocks comparatively near the surface, in a manner suggestive of a huge Gifford injector; but it does not seem possible that such enormous quantities of water could suddenly find their way into the lava against the pressure of gases associated with the eruption.

These difficulties disappear, however, if we conceive of water as being suddenly carried by fissuring and subsidence of the earth's crust into the deeper regions where temperatures corresponding to a red heat prevail.

There is abundant evidence that fissuring and subsidence are connected with volcanic activity, and it is believed that volcanic eruptions as well as the formation of thermal waters are merely the exterior manifestations of disturbances of chemical and me-

[1] No account appears to be taken of the view held by Major C. E. Dutton and others, that volcanic activity may be connected with the development, relatively near the surface, of temperatures greatly above those of the normal gradient. F. L. R.

chanical equilibrium in depth. In order to make clear the relations which connect the instability and irregular subsidences of the deeper portions of the earth with volcanic eruptions and thermal waters it is necessary to review some earlier observations of mine on the constitution of crystalline rocks and on the curious results of heating them.

I showed in 1899 and 1902 that when powdered igneous rocks (granites, porphyries, trachytes, gneisses, gabbros, etc.) are raised to a red heat in a vacuum they give off water and gases among which hydrogen and carbon dioxide predominate. Contrary to the belief of Bischof and Delesse this is not imbibed or quarry water, which can be driven off by heating to 150° or 200° C. in a vacuum, but is water of constitution. Its elements are strongly combined, as hydrates or otherwise, in the minerals of the rocks. The quantity of water lost at red heat varies from seven grams per kilogram in granite to nearly seventeen grams per kilogram in lherzolite. With the water there is driven off from three to eighteen times its volume of gases which, as I have shown, are only in small part included gases, being produced mainly by the action of the ferrous salts in the rock upon vapor of water at a red heat. The gases thus given off are similar to volcanic gases, as may be seen from the following table:

ANALYSES OF GAS FROM ROCKS AND OF VOLCANIC GAS.

	Gas Extracted from Rocks at Red Heat.				Volcanic Gas.	
	Granite (Vire). (Gautier).	Porphyry (Esterel) (Gautier).	Ophite (Villefranque) (Gautier).	Gneiss (Seringapatorum) (Tiden).	Mt. Pelé (Moissan).	Santorin (Fouqué).
Free hydrogen.	77 30	31.09	56.29	61.9	22.3	16.12
Carbon dioxide.[1]	14.80	59.15	35.71	31.6	44.2	50.41
Carbon monoxide.	4.93	4.20	4.85	5.4	4.5	——
Marsh gas.	2.25	2.53	1.99	0.5	15.7	2.95
Hydrogen sulphide.	trace	0.00	0.45	0.0	0.0	trace
Nitrogen.[2]	0.83	2.10	0.68	1.6	12.2	30.32
Ammonia.	trace	trace	trace	——	trace	trace

[1] With a little oxysulphide of carbon.
[2] With argon.

Thus the gases which I have extracted from rocks are composed of the same constituents as the volcanic gases. The vapor

of water, free hydrogen, and carbon dioxide predominate in both, and both contain carbon monoxide, marsh gas, nitrogen, a little hydrogen sulphide, and traces of cyanogen and of petroleum compounds. This analogy of composition suggests an analogous origin.

We are now in a position to ask what will happen if in consequence of fissuring and subsidence a given mass of crystalline rock be brought suddenly into a region of the crust where the temperature is above that of red heat or if, as a result of such disturbance of equilibrium, it be rapidly injected with molten magma.

When rocks are thus quickly raised to a temperature approaching or exceeding that of red heat, superheated steam forms which reacts on the minerals of the rock, as experimentally shown, with the disengagement of gases. The magnitude of this process is far greater than one might suppose. The quantity of water set free when granite is brought to a red heat is at least twenty-five to thirty million metric tons for each cubic kilometer of this rock, which is the least rich in water. Reduced to vapor, this water would occupy at 100° C. a volume of 43,000,000,000 cubic meters and at a temperature of 1100° C. a volume of 160,000,000,000 cubic meters. At the same time, according to my experiments, there will be evolved 7,000,000,000 cubic meters of gas calculated at 0° C. and about 28,000,000,000 cubic meters calculated at 1100° C. A minimum pressure of 7,000 atmospheres would be attained. This figure, it may be noted, is of the same order of magnitude as that given on page 689 as the probable minimum pressure at the depth whence lavas are derived.

If one takes account of the well known fact that the temperature of the earth increases with depth at the rate of one degree for thirty to thirty-two meters, he can see what powerful phenomena of pressure and of ejection of water and gas would take place were a cubic kilometer of granite suddenly carried down to a depth of 25,000 or 30,000 meters and injected with molten magma. The pressure suddenly developed would be enormous

and would tend to drive the lava to the surface. Inasmuch as volcanic eruptions, according to this view, would be regulated only by the chances of deep-seated rupturing or subsidence the irregular periods separating successive eruptions of the same volcano become susceptible of explanation.

Faulting and subsidence of sufficient magnitude to subject large masses of crystalline rocks to changes of temperature capable of producing such results as those outlined are within the range of geological observation. As examples may be cited the depression of the Black Sea, the engulfment of part of the island of Krakatoa, over nine cubic kilometers, in 1883, the Tertiary subsidence of the Rhine valley, the basins of the great African lakes and of the Mediterranean, and the enormous subsidence of the bed of the Pacific Ocean. Historians and geologists alike testify to the connection between such movements and volcanism.

In studying the mechanism of the genesis of hot saline waters we find that their salt is derived from igneous sources—it is newly formed. As to the water which volcanoes furnish so abundantly, we have shown that it cannot result from the direct or capillary penetration of meteoric or marine water. Such an hypothesis is neither reasonable nor necessary. The great eruption of Etna in 1865 supplied the enormous volume of 11,000 metric tons of water a day for two hundred days, or a total of over 2,000,000 tons for this critical period. I have shown that a cubic kilometer of granite would furnish, at red heat, from twenty-five to thirty million tons of water. One-fourth of this volume of rock would thus suffice for the total eruption of Etna in 1865. De Launay estimates that the principal thermal springs of France discharge a total of 700,000 hectoliters of water in twenty-four hours. The water which issues from a single cubic kilometer of granite raised to a temperature of 600 or 700° C. would suffice to keep all these springs running for a year with a flow of 48,500 liters a minute.

In short, many moderate subsidences in the deeper layers of the terrestrial crust suffice to account for the formidable pressures developed in volcanic eruptions and for the quantities of gas and water ejected as vapor or as thermal springs.

I shall now proceed to show that subsidence, dislocation or crushing, accompanied by sudden heating of masses of rock, is not necessary to insure the continuance of thermal springs. For this purpose we will consider a layer of gneiss or granite at a depth where the temperature is such that the water of constitution is beginning to escape. Each time that, in consequence of folding, faulting or subsidence, a part of this layer is lowered, and consequently heated, or each time that some increase in the pressure of overlying beds causes molten magma to approach the layer in question, there will be an increase in the evolution of water and gases. These will tend to escape and the enormous pressure developed will in turn push back the magma that caused the elevation in temperature and the layer of rock will cool. As the temperature falls, the constituents of the rock that had been dehydrated at red heat will slowly recover, by virtue of chemical affinity, the water that they had lost, taking it perhaps in part from emanations rising from a deeper, hotter zone and in part from overlying, less dehydrated rocks. These in turn will recoup themselves from layers above and the process will continue upward to the zone into which water from the surface can penetrate by imbibition or capillarity. We thus see that the cause of the penetration of water from the surface into the deeper regions of the globe is not gravity or capillarity but chemical affinity.

If then volcanic eruptions are occasioned by the sudden heating of rock masses from which in consequence of deep subsidence or invasion by molten magma the water of constitution is suddenly freed, no such violent action is necessary for the formation of thermal springs. These may be explained as a kind of gentle distillation of crystalline rocks in a region so hot that water of constitution tends to escape upon a slight increase in temperature.

We may pass now to the chemical reactions that give rise to thermal waters and volcanic exhalations. I have observed in my experiments that all ferrous salts of iron in the presence of vapor of water at a red heat (and often below a red heat) change to ferric salts or to ferric or ferro-ferric oxides, with the liberation of hydrogen. The chlorides, carbonates, silicates, etc, of iron

change to oxides or ferro-ferric or ferrous silicates. The sulphide of iron changes to magnetite with the evolution of abundant hydrogen sulphide mixed with hydrogen and sulphur:

$$3FeS + 4H_2O = Fe_3O_4 + 3H_2S + H_2$$
$$H_2S = H_2 + S \text{ (at red heat)}.$$

With the sulphides of metals that do not decompose water, a similar reaction takes place, but only in the presence of silica or silicates:

$$PbS + H_2O + SiO_2 = PbSiO_3 + H_2 + S.$$

In the case of ferrous silicates (olivine, hornblende, pyroxene, etc.) reactions similar to the following take place:

$$9SiO_3Fe + 4H_2O = 3(SiO_3)_3Fe_2 + Fe_3O_4 + 4H_2$$

Normal ferrous silicate. Ferric silicate. Magnetite.

To the decomposition of vapor of water by these silicates and by other ferrous salts are due the gases, rich in hydrogen, produced when crystalline rocks are raised to red heat. The emission of this gas at the surface of the earth I attribute largely to the same cause although there is doubtless an independent and continuous exhalation of hydrogen from the central nucleus of the globe.

Water itself could not exist in the incandescent metallic mass, dominantly iron, which forms the nucleus of the earth. From that nucleus issue continuously, not water and carbon dioxide, but hydrogen and carbon monoxide. The latter unites with sulphur from the same source to form oxysulphide of carbon which has been found in volcanic gases and in small quantities in some thermal springs. At a lower temperature, farther from the center of the globe, this oxysulphide of carbon mostly disappears:

$$COS + H_2O = CO_2 + H_2S.$$

Such is the origin of carbon dioxide and hydrogen sulphide. The latter may also form by direct union of hydrogen and sulphur at a dull red heat. The carbon monoxide of volcanic gases

may result from the well known reaction of a metallic carbide on an oxide:

$$3Fe_2C + Fe_2O_3 = 3CO + 8Fe,$$

or

$$Fe_2C + CO_2 = 2CO + Fe_2.$$

We know that these metallic carbides which (like the nitrides which accompany them) resist the highest temperatures, occur in the profound depths of the globe. With the oxides they give at red heat carbon monoxide, water, methane or marsh gas and petroleum compounds.

The reactions which we have discussed and which we have observed in the laboratory, give rise to a series of gaseous reducers which impregnate the abyssal rocks under an enormous pressure. These are hydrogen, carbon monoxide, oxysulphide of carbon, and hydrocarbons. Between these substances and the vapor of water, the vapor of sulphur, hydrogen sulphide, and carbon dioxide a mobile equilibrium, dependent upon temperature and above all upon the relative masses of the bodies reacting at any one place, is established, by means of reversible reactions. It should be noted that the formation of water, carbon dioxide and sulphur dioxide takes place at profound depth in the complete absence of free oxygen. The water results from the reduction of the oxides and of carbon dioxide itself, by hydrogen exhaled from the region of incandescence and the sulphur dioxide from the action of hydrogen sulphide upon vapor of water at a red heat. It is difficult not to admit also that chloride of sodium which formerly issued in such great abundance from the incandescent terrestrial hearth does not still escape as vapor. It is known, with hydrochloric acid, in all lavas and in the hottest fumaroles.

It has been shown that the sodium chloride of thermal springs cannot have been derived from the ocean. Original in the central nucleus of the planet, chloride of sodium has been at all epochs the vehicle of the metals which it transforms into volatile chlorides. Whether these metals are free, whether they are oxides or sulphides (which the vapor of water transforms, as

has been shown, into oxides) in the presence of alkali chlorides, water, and silica, these metals or their salts pass, at red heat, into volatile chlorides with the formation of a soluble alkali silicate:

$$PbS + H_2O + 2NaCl + SiO_2 = Na_2SiO_3 + PbCl_2 + H_2 + S.$$

With the other gases and vapors, these volatile chlorides penetrate the rocks and at higher levels, where the vapor of water can liquefy, give rise to new reactions whereby sulphides, carbonates, silicates, etc., are formed, which owing to their slight solubility in water are deposited from aqueous solution in metalliferous veins. Such is the mode of transport of these usually fixed and insoluble metallic compounds. Since the earliest geological periods the more volatile of the chlorides, those of tin, titanium, antimony, etc., have been carried with vapor of water, hydrogen sulphide and other gases through fissures in the older crystalline rocks and have been deposited in some cases as oxides (rutile, cassiterite), in others as sulphides (stibnite) according to the predominance of water or of hydrogen sulphide.

Long ago Gay-Lussac and Thenard showed that when a mixture of alkali chloride and silica is raised to red heat, an alkali silicate and hydrochloric acid result. Besides, we have seen that the metallic sulphides when heated to redness in the presence of water or its elements and silica change to silicates. If then, alkali chlorides, metallic sulphides or chlorides, silica and water be brought together at red heat, away from oxidizing influences, a double silicate forms with liberation of hydrochloric acid and hydrogen sulphide, or rather, hydrogen and sulphur:

$$FeS + 2KCl + 2SiO_2 + 2H_2O = K_2SiO_3,\ FeSiO_3 + 2HCl + H_2S.$$

In this manner are formed the double or triple silicates that constitute the minerals of the igneous rocks. The deep-seated disengagement of hydrogen, hydrochloric acid, sulphur dioxide, hydrogen sulphide, and vapor of sulphur is thus a complementary phenomenon to the formation of the rock-making silicates

which are continually produced at the expense of the metallic vapors that rise from the central nucleus. These phenomena pass continuously from the central nucleus into the region whence lavas issue, where rocks begin to solidify and where thermal waters receive their mineralization.

We have seen how water may be newly formed at the expense of hydrogen emanating from the central region of the globe. As to the silica, which, with water, is the great agent of mineralization, the most probable hypothesis is that it is derived from chlorides, sulphides or nitrides of silicon from the igneous reactions of the terrestrial nucleus. Water (or its elements) decomposes these substances into silica and hydrochloric or sulphydric acids, or in the case of silicon nitride, into silica, ammonia, nitrogen and hydrogen. Such seems to be the origin of an important part of the silicates and of the nitrogen and ammonia which issue from all volcanoes and are found also in thermal waters. The nitrogen of the atmosphere seems to be, with hydrogen, the complementary product of the geological formation of silica and the silicates.

I observed in 1888 that when natural double or triple silicates are heated to redness with hydrogen sulphide, with a mixture of vapor of sulphur and marsh gas, or with sulphide of carbon, sulphosilicates are formed. Such sulphosilicates are probably produced at greater depth by reactions of hydrogen sulphide or sulphur on the silicates and persist as long as the sulphurous vapors preponderate. Later, owing to the partial disappearance of the hydrogen sulphide and sulphur by combination with surrounding materials or by escape through fissures as gases, or to the lowering of the temperature, the sulphosilicates are decomposed by water to insoluble silicates, alkali sulphides and hydrogen sulphide:

$$\underbrace{Al_2O_3, Na_2S, 3(SiO_2, SiS_2)}_{\text{Sulphosilicate corresponding to albite.}} + 8H_2O =$$

$$\underbrace{Al_2O_3, 2SiO_2, 2H_2O}_{\text{Kaolin.}} + 4SiO_2 + Na_2S + 6H_2S.$$

Thus originates the alkali sulphide of sulphurous thermal waters.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, South Bethlehem, Penna. The full name of the author should be attached to all communications.

SKETCH OF THE GEOLOGY AND ORE-DEPOSITS OF THE CHERRY CREEK DISTRICT, ARIZONA.

DISCUSSION OF PAPER BY JOHN A. REID.

Sir:—Many important and interesting subjects are brought up in the paper by Mr. John A. Reid, published in the March–April number of ECONOMIC GEOLOGY. Not of the least of them is one on which comparatively little emphasis is laid by the writer, namely, the age of the deposits. The discovery of pre-Carboniferous and by inference pre-Cambrian mineral deposits in Central Arizona, widens in a most desirable manner our knowledge of this little known group, comprising the "ancients" in a complex of which by far the greater number are of Cretaceous and Tertiary—or even Quaternary age.

The first of the pre-Cambrian deposits discovered in the west were the Homestake lodes of South Dakota; later Spencer and others found their equivalents in Wyoming; and still later, during 1905, I recognized a few pre-Cambrian copper and gold deposits from New Mexico (*Science*, May 4, 1906) to which a considerable number were later added by Mr. L. C. Graton, my collaborator in the same field.

The Bradshaw quadrangle, of which the geology has been studied by Messrs. Jaggar and Palache, lies just to the south of the Cherry Creek district in Arizona, described by Mr. Reid. No

positive proofs of the age of the deposits were obtainable in the Bradshaw Mountains, and consequently, this was left an open question. An examination of the data available suggests to me strongly that two classes of deposits are present: first, a pre-Cambrian group of copper lodes, and second, a much later group of gold deposits connected with intrusions of granodiorite or quartz diorite.

The discovery of widely spread pre-Cambrian deposits in the west emphasizes the fact that the Cordilleran region is a "metallogenetic" province of great antiquity in which repeated eruptions of igneous rocks were successively followed by epochs of vein formation. Among these oldest deposits low grade gold and copper ores seem to predominate.

On page 433 Mr. Reid states that "in the typical copper veins the oxidized zones contain copper minerals, often in great abundance, and outcropping on the surface as at Globe, Bisbee and Clifton." As far as Clifton is concerned this is only partially correct, for at that place the largest ore bodies of chalcocite underneath Copper Mountain do not crop at the surface but are there merely represented by sericitized porphyry filled with veinlets of quartz, so that here also is an excellent example of the barren surface zone of which Mr. Reid speaks. On the other hand, many of the smaller veins at Clifton, as well as the oxidized contact-metamorphic deposits in limestone, have prominent surface croppings of oxidized ores.

W. LINDGREN.

WASHINGTON, D. C., June 18, 1906.

THE PROBLEM OF THE METALLIFEROUS VEINS.

NOTE BY THE AUTHOR.

Sir:—In a paper by the undersigned, published in ECONOMIC GEOLOGY for December–January, pp. 229–230, the following statement appears in connection with the general discussion of hot-springs: "Professor Suess . . . delivered an address a few years ago at an anniversary celebration in Carlsbad, Bohemia, in which he maintained that in the Carlsbad district the natural catchment basin was insufficient to supply the waters and that

both the unvarying composition and amount through wet seasons and dry were opposed to a meteoric source."

It sometimes happens that in citing another writer, the one who makes the citation may not express exactly what the original text was intended to convey, and the accurate equivalency may be especially impaired if a translation is made from one language into another. In order to avoid any possible misconception of the point above stated, since it is a very important one regarding hot-springs and one which has received far too little attention, I submit the exact passage. I take it from the "Naturwissenschaftliche Rundschau" for November 13, 1902, p. 585. Professor Suess cites with apparent approval and support the results of Rosiwal as follows: "Rosiwal vermöchte keine Uebereinstimmung zwischen dem Gange des Niederschlages und der Ergiebigkeit der Quellen von Karlsbad zu finden."

It is possible that this statement that Rosiwal could not detect any agreement between the run of the rainfall and the outflow of the Karlsbad springs, may merely mean that there was no increase of the latter in wet seasons nor decrease in dry, but as I first read it the idea conveyed was that the rainfall bore no relation to the springs, or was not sufficient for them in the available catchment area.

J. F. KEMP.

COLUMBIA UNIVERSITY,
NEW YORK.

WHAT IS A FISSURE VEIN?

Sir:—The history of words in common use is generally interesting, and that of the names applied to veins is no exception.

Of the terms "gash vein" and "true fissure vein," which are quite often attributed to Whitney, as they have been in the discussion of veins now being carried on in this journal, the first term, "gash vein," at least, was in use a considerable time before Whitney's "Metallic Wealth of the United States" appeared.

On page 67 of a work by Westgarth Forster, published at New Castle in 1809, and entitled "A treatise on a section of the strata, commencing near New-Castle-upon-Tyne and concluding on the

west side of the mountain of Cross-Fell—with remarks on mineral veins in general," etc., he uses this language:

> The gash or chasm veins, on the contrary, are always wide above (as at A, Fig. 5) and grow narrower as the sides or cheeks come closer together, as they are worked down at uncertain depths; and they often close or check out altogether (as at B).
>
> The gash vein is not so subject to twitches in the line of bearing as the slips, etc.

By "slips" he means veins along fault planes.

Forster then gives as an example of a gash vein a rich lead vein at Llangunog in Wales, which terminated abruptly at a "black schistus, or shiver, or plate." On page 68 he says:

> From what has been said of the gash vein, it appears that this species of mineral vein is easily described, it being an open fissure in the rock, generally running in a straight line, often nearly perpendicular, and always wider above than below, at a considerable depth, if we go deep enough to know it (as in Fig. 5).

Unfortunately the figures referred to are missing from the volume to which the present writer has access. This definition was quoted and used by Robt. Were Fox in an article "On Mineral Veins" published in the Fourth Ann. Rep. of the Royal Cornwall Polytechnic Society, Falmouth, 1836, p. 97. Whitney's definition[1] came out eighteen years later, and is merely a modification.

> *Gash Veins.*—This variety of mineral deposit holds an intermediate place between segregated and true veins. Like the latter, they occupy pre-existing fissures; but these are of limited extent, and not connected with any extensive movement of the rocky masses. They are usually confined to a single member of the formation in which they occur, terminating below, when a marked change in the lithological or mineralogical character of the rock takes place.

Whitney, I believe nowhere defines the term "true fissure vein," but gives a definition of "true veins" thus:[2]

> *True Veins.*—A true vein may be defined as a fissure in the solid crust of the earth, of indefinite length or depth, which has been filled more or less perfectly with mineral substances; or, in other words, an aggregation of mineral matter, accompanied by metalliferous ores, within a crevice or fissure which

[1] Whitney, J. D., "Metallic Wealth of the United States," Philadelphia, 1854, p. 48.

[2] *Op. cit.*, p. 49.

had its origin in some deep-seated cause, and may be presumed to extend for an indefinite distance downwards.

On pages 43, 49, 57, etc., he seems to use "true vein," "fissure vein," and "true fissure vein," indiscriminately. Neither of the first terms were new with Whitney, and if the third was, it was apparently accidental, for in later works he uses the term "true vein" to distinguish the veins reaching to great depths from the shallower ones, as in his "Geology of the Lead Region."[1]

His definition of "true veins" was merely a variation of one given by Joseph Carne in October, 1818, thirty-six years before,[2] as follows:

> By a *true vein,* I understand *the mineral contents of a vertical, or inclined fissure, nearly straight, and of indefinite length and depth.* These contents are generally, but not always, different from the strata, or the rocks, which the vein intersects. True veins have usually regular walls, and sometimes a thin layer of clay between the wall and the vein; small branches are also frequently found to diverge from them, on both sides.

So that he can in no sense be called the author of "gash vein," and if he was of "true fissure vein" it was probably unintentional.

FRANK L. HESS.

WHAT SHOULD APPEAR IN THE REPORT OF A STATE GEOLOGIST?

Sir:—The answer to your question, "What should appear in the report of a State Geologist?" lies, as it seems to me, in a correct conception of what a State geological survey should do. The report, or reports, should contain the results of the survey presented in convenient and accessible form. An examination of the laws governing a number of State geological surveys indicates that they are designed to carry on studies of the mineral resources of the States with a view to (*a*) Exploration and (*b*) Exploitation. Legislators in appropriating money for the foundation and maintenance of such bureaus evidently have in mind the strictly utilitarian purpose of stimulating development of the

[1] Geol. Sur. of Ill., Vol. I, 1866, p. 191.

[2] Carne, Joseph, "On the Relative Age of the Veins of Cornwall, *Trans. Roy. Geol. Soc. Corn.,* Penzance, Vol. —, 1822, p. 51.

natural resources of the State. When the educational phases of the work are mentioned in the governing act it is usually incidentally only. It is the duty of all officers to carry out the purpose of the law and to loyally observe its intent. The State geologist should therefore shape his work to the primary purpose of stimulating development of the State's resources; whereby the taxable property being increased the tax rate may be decreased. Incidentally full advantage should be taken of the opportunity to make the work of benefit educationally and to realize all other indirect benefits possible.

Intelligent exploitation can only follow intelligent exploration, and since private initiative may usually be relied upon for the one, the State survey may well make the other its own main duty. Exploration, in the generally accepted sense of travel through wild and uninhabited districts, nowadays seldom falls to the lot of the State geologist. By a paradox it is only the more settled and richer States that feel able to afford geological surveys. Exploration, however, may properly be used to cover the whole range of field investigation and we may even include a certain amount of laboratory research without doing violence to the term. In general exploration should be directed to the determination of, (*a*) the distribution, (*b*) the mode of occurrence, (*c*) the value, of each of the mineral resources of the State. Studies of distribution should be not only geographical but geological. It is as important to know in what particular strata to look for a given ore as in what county, and it is in the geological investigation that the special knowledge of the officers of the survey is most useful. The investigation of the mode of occurrence is necessarily a broad one, calling for a careful study of the stratigraphy and geological history of the district. The purpose of this investigation is to develop rules for prospecting and developing in each instance, and this purpose should be kept steadily in view in order that the whole results may be focused upon it. Studies of the value of the deposit are in part scientific and in part commercial. The genesis must be understood so as to intelligently estimate the probability of extensions and of continuance with depth of an ore body. It is very important to know in the case

of a coal outcrop whether it is an isolated pocket or the edge of a large body. Not less important, however, are relations to transportation, ease of stripping or mining, quality as compared with competing material, cost of production, extent of market, and other matters of commercial and economic importance. There is a wide range of opinion as to how far the State survey should go in the investigation of problems of this sort, and probably no hard and fast rule can be laid down. There are none-the-less certain principles to be kept in mind. One of these is to avoid duplication of work. So much is to be done and the funds are usually so limited that there is rarely any justification for taking up work already provided for. The main duty of the survey is to gather and disseminate information not otherwise accessible, but since the people within a State come to look to their own survey for a wide range of information it may properly republish or arrange for joint publication of information collected by other agencies; carefully preparing it for the particular purpose and audience to be reached. In the second place all such information must be authoritative. There are many excellent geologists who are not prepared to give opinions of value on these subjects and in such cases recourse should be had to experts called in for temporary service. One inaccurate or misleading report discredits a whole series of excellent volumes.

With these principles in mind the content of the reports themselves may be briefly discussed. The form and style of publication is generally fixed by law, but where it is left to the option of the State geologist the dual character of the work would seem to be best met by the publication of bulletins or advance reports dealing with particular subjects or districts, followed by carefully planned and maturely developed systematic reports by large districts, by geologic systems, or designed to meet particular needs; such as a hand book of the geology of the State for the use of schools.

There are particular phases of the work which demand especial notice.

If it is at all practicable without duplication of work, statistics of production should be regularly collected and published. No

one thing brings the survey into as close relations with producers and makes more for an intelligent interest in the work.

Topographic surveys are usually so expensive, and as now carried on are so much more useful for engineering and general purposes than for geologic work, that it is a question whether a State survey had not better let them entirely alone. They are valuable enough to find support independently and strictly on their own merits.

Many of the older State surveys were shipwrecked by attempting to carry too heavy a load of fossils and it would seem proper that paleontology as such should be left to the museums and colleges. Paleontology as an aid to stratigraphy should be strongly supported and constantly used, and a reasonable amount of descriptive paleontology may properly be published as a portion of the description of a formation. Under present conditions, however, and in the light of the past, it is a question whether a State survey is warranted in undertaking the investigation of purely paleontologic problems and the publication of paleontologic monographs.

In general it should be remembered that money is given a survey for the application of science rather than for research, though this is not usually interpreted in any narrow or mean sense. The acceptance of the money, however, implies a contract to be faithfully fulfilled and to divert to purposes of scientific research, however important, funds appropriated for the development of natural resources is not only unwise and destructive to the life and usefulness of a survey, but malfeasance of office, and should be condemned as such.

H. F. Bain.

REVIEWS

British Guiana. Science and Agriculture Department. Report on the Petrography of the Cayuni and Mazaruni Districts and of the Rocks at Omai, Essequibo River. By J. B. HARRISON. With some notes on the geology of part of the Berbice River. By C. W. ANDERSON. Georgetown, Demerara, 1905.

Attention might be called to the excellent chemical and petrographical work being done by the government geologist of British Guiana. The present report contains a large number of rock analyses that are practically of the same high standard as those made for the U. S. G. S. Careful assays have also been made of the gneisses, schists and intrusive rocks of these gold districts. The results of these assays indicate that gold up to seventeen grains per ton and silver up to seventy-seven grains per ton are present in nearly all the country rocks. The assays appear to have been made on samples of fresh rock, although in the case of some amphibolites and hornblende schists it is stated that "the gold occurs in two ways, firstly as a constituent of the heavy minerals, secondarily as free gold in the numerous veins and veinlets of quartz which traverse them."

F. L. RANSOME.

The Production of Precious Stones in 1904. By GEO. F. KUNZ. Extract from Mineral Resources of the United States, Calendar year 1904. Washington, 1905. Pp. 120.

The Production of Precious Stones in 1905. By GEO. F. KUNZ. Extract from Mineral Resources of the United States, Calendar year 1905. Washington, 1906. Pp. 40.

Gems, Jewelers' Materials and Ornamental Stones of California. By GEO. F. KUNZ. Bull. No. 37, Calif. State Mining Bureau, Sacramento, 1905. Pp. 171, Figs. 51 and 4 colored plates.

California Mines and Minerals. By CHAS. G. YALE. California State Mining Bureau, Sacramento, 1905. Pp. 56 with map.

The four papers, the titles of which are given above, present an excellent synopsis of the condition of gem mining in the United States at the present time. The first two describe the progress made in the search for precious stones throughout the country during the past two years while the last two discuss in detail the gem materials of the most important of the gem producing states.

Following the custom of previous years the collection of the statistics relating to the precious and ornamental stones of the United States during 1904 and 1905 was entrusted by the National Survey to Mr. Kunz. The result is the usual full discussion of all the developments that have taken place during the years in the field covered.

The total yield of the forty-seven precious and ornamental materials investigated was $324,300 during 1904 and $326,350 during 1905. Of these aggregates by far the greater amounts were contributed by sapphire, turquoise and tourmaline. Of the first and last of these the values mined are increasing gradually from year to year, while the value of turquoise placed upon the market is diminishing.

During 1905 olivine began to assume an important role among American gems, no less than $10,000 worth having been obtained from the mines at Talklai, Gila Co., in Arizona.

The most important discoveries during 1904 were made in the new gem district in Southern California, notably in San Diego County. Here there were found beautiful blue and white topazes, as fine as those from Siberia, a single crystal weighing more than a pound; pale to dark sea-green beryls and rose beryls; axinite, heretofore not known in gem quality in this country; red and green tourmalines, and transparent epidotes.

Fine mineral specimens (not, however of gem quality) have been obtained at a number of places, especially fine tourmalines at Paris and Rumford Falls, Me., and at Haddam Neck, Conn. Kunzite was not mined as extensively as during 1903, but the

sapphire mines in Montana, and turquoise mines in New Mexico still maintain a steady yield.

The Yogo dike at Yogo Gulch, Montana, is judged to be the greatest gem mine in the world. It is estimated to contain at least 10,000,000 cu. ft. of material. Up to the present time the work in it has been merely in the nature of exploration. The 'stones' are found in the weathered rock which is soft and therefore easy to mine. The gems are of small size averaging from one-half carat to three carats when cut. They are brilliant, free from flaws, and they vary in color from light shades to deep blue. 'Culls' are produced abundantly but not in sufficient quantity to meet the demands. They sell at from $2 to $6 per oz.

In Utah about thirty-five miles southwest of Simpson Springs a few crystals of red beryl were obtained. These were associated with topaz, bixbytite and garnets in a rhyolite. Blue beryls are being found in small quantities at Spruce Pine, N. Carolina.

The tourmaline localities in Maine are described as being very similar to the California occurrences, discussed below. The veinstone is a pegmatite lying between a mica-schist and a gneiss. The vein is in three parts, of which the upper is graphic granite containing no lithia minerals. The bottom layer is a zone of orthoclase with some black tourmaline and quartz. The central zone, which is the mineral layer, is composed of large masses of quartz, muscovite and cleavelandite. Lepidolite and the gem minerals, beryl and tourmaline, occur here in pockets. These pockets vary in size from that of an egg to that of a barrel. The outer zones of minerals in the pockets are quartz and tourmaline on the lower side and quartz and muscovite above. Toward the centers of the pockets lepidolite takes the place of muscovite, and cleavelandite replaces quartz. The tourmalines usually occur in a brown mud or in a pink clay resembling montmorillonite. Occasionally they are found in quartz. The beryls usually occur in this mineral and rarely in the centers of the pockets. When garnets are plentiful tourmalines are absent. Projecting inward from the walls of the pockets are crystals of quartz, tourmaline

and apatite. The tourmalines are usually either deep green or sapphire blue. The apatites are purple, pink or blue, the first named variety always being the oldest. When the pink variety is present in large quantity tourmalines are absent. In one case a pink apatite was discovered around a tourmaline crystal and penetrating its mass along cracks.

At the Mount Mica locality during 1905 some fine gems were obtained, but the most notable find was that of a large tourmaline fifteen inches long, seven inches in diameter and weighing thirty-one pounds. "Its summit is formed of many well defined prisms, of a clean grass-green color, separate at first, but soon united into a solid column, changing in color to a dark blue, and coated with a multitude of minute tourmalines tinged with pink."

A new locality for colored tourmalines is reported as the Strickland quarry, Portland, Connecticut, a few miles from Haddam Neck. Up to the present time only green varieties have been found, but one of these was very large.

Probably the most important find recorded in 1905 is that of a new occurrence of Utahlite (variscite), twenty miles N. W. of Mercur, Tooele County, Utah and eight or nine miles west of Stockton. The mineral which is of a bright green color, occurs in nodular masses from the size of a lemon to that of a cocoanut, enclosed in a reddish brown quartzite.

Among the interesting notes descriptive of single mineral localities the author mentions the occurrence of turquoise in tiny veins in the incline shaft of the American Copper Mining Company on Watchung Mountain, New Jersey. The shaft follows the contact between 'trap' and altered Triassic shale.

Amber is now being obtained in some quantity from the Cretaceous clays near Kreischerville, near the southwestern end of the Staten Island, New York. The material occurs in lignite and charred wood which form a layer about three and one-half feet thick near the base of the exposed section of the clay. It occurs also in the Cretaceous coals at Eagle Pass, Texas, and in Terlingua Creek in pieces as large as a grain of corn.

The gem deposits of California are described in outline in the Extract from the Mineral Resources, and in detail in the bulletin

of the California State Mining Bureau. The bulletin divides the State into four mineral districts: (1) The gold region of the central and northern counties along the western base of the Sierra Nevada. In this are found gold-quartz and occasionally diamonds. (2) The second district centers around Visalia in Tulane County. Here occur chrysoprase and ornamental forms of quartz, garnets and the new variety of vesuvianite named by the author californite. This mineral resembles very closely the rare material jade. It occurs also in Siskiyou County. (3) The third, and richest, district is the desert region in the southwest. In this arid country, largely covered by volcanic rocks, are the turquoise mines. In San Bernardino County, about one hundred miles northwest from Needles and fifty miles north of Manvel, are three groups of mines, some of which are on the sites of prehistoric workings. A group of five other mines is sixty miles west of Manvel in a "bird's eye porphyry." The turquoises are found in pockets in this rock surrounded by a white friable substance said to be a lime silicate. (4) The fourth, and the most interesting district, is that recently developed in San Diego and Riverside counties where lithia minerals, axinite, beryls and essonite garnets are associated in specimens of gem quality and in sufficient quantity to warrant working. The gems occur in pegmatites cutting a gabbro or diorite. They are found in pockets in the pegmatites either embedded in clay, or quartz or orthoclase, or they may be attached to the walls of the dyke. Generally the pegmatite on one side of the pocket is coarser grained than on the other which is fine grained and finely banded with lines of small brown garnets or tourmaline. These facts suggest to Professor Hopkins that the pegmatite is a vein rather than a dyke. The geological structure of the district is outlined and a description is given of the paragenesis of the minerals at each mine center.

Although a discussion of the gem localities of a single State, the descriptive portions of the bulletin contain excellent accounts of most of the minerals used at present as gem materials. These are embellished by photographs and colored plates of the gem minerals of California. Naturally the greatest amount of space

is devoted to the remarkable lilac-colored or pink spodumene (Kunzite) on Pala Chief Mountain, and its behavior under the influence of different types of rays. Here we find the most complete account of this mineral that has yet appeared.

The fourth title is that of a small pamphlet dealing exclusively with mineral statistics. W. S. BAYLEY.

Geology of the Tonopah Mining District. By JOSIAH EDWARD SPURR. Professional Paper No. 42, U. S. Geological Survey, Washington, 1905, pp. 296.

Long ago the gold and silver pouring out from the Comstock, Eureka and Tuscarora mines made the state of Nevada famous. After a sleep of thirty years, undisturbed by scoffing references to conditions of decay, she has awaked and once more opens her wonderful treasure vaults. Tonopah, Goldfield, Searchlight and other camps have vindicated the reputation of the desert state, and impressed the world by their production. No longer is the geologist under the necessity of confining himself to "obituary notices" of decadent camps. Tonopah, for one, is very much alive and the report on its geology and mineral resources by Mr. Spurr is a timely publication which will be read with much interest by mining engineers and geologists.

In brief, it is a most excellent report in its elements of practical utility, in its contributions to the advance of mining geology, in its careful maps and drawings, and in its general typographical appearance. It would probably be correct to characterize it as the best of the reports which Mr. Spurr has written.

The first question asked by the reader is likely to refer to the general location of Tonopah. Little information is obtainable from the report in regard to this, as it contains no map for general orientation—a rare sin of omission in the publications of the Geological Survey. One misses also a statement of the total production of the mines since discovery.

The geologic features are described on about forty pages. Only volcanic rocks occur in the district; the productive formation consists of a relatively small area of hornblende-biotite andesite; the andesitic eruptions were followed by a closely con-

nected series of flows and intrusion of rhyolites, the more basic members of which are called dacite. A detailed study of the relations of these rocks led Mr. Spurr to the conclusion that the original magma had about the composition of the productive andesite, and that this has split by differentiation into a more basic andesite and a dacite; by continued differentiation the rhyolites and basalts were obtained from the latter. This view is doubtless well founded and a generalization is extended to cover the igneous relations of the whole province of the Great Basin. The latest of the Tertiary formation consists of lacustrine beds of igneous material.

Complicated faulting of various types was initiated by the intrusion of the dacites and by the collapse following the eruptions in general. Here again a tentative generalization follows in the statement that probably much of the faulting in the Great Basin is due to such causes. The fault blocks are outlined on the geological map—a work of much detail and difficulty which every geologist will appreciate upon inspection of the map. If withal the fault blocks look a trifle artificial, this is no doubt due to the fact that some faults have been extended and connections made on the basis of general probability (p. 80). It would probably be better to indicate such lines by dots or dashes in contradistinction to definitely traced dislocations.

The mineral deposits occur as quartz veins of replacement types along short, linked fissures and shear zones in the earlier andesite, while the later acidic eruptions only contain poor or barren veins. This simple statement is of great economic importance, and in view of the prevalent rock alteration its establishment no doubt involved much and painstaking work. The vein filling consists of quartz with some sericite, carbonates and adularia. The ore minerals are argentite, polybasite, stephanite, a silver selenide, and gold in alloy with silver. The common sulphides, including pyrite, are not abundant.

As ascertained from the recent statistics for 1904 of the Geological Survey, the principal operators were the Tonopah Mining Co., Tonopah-Belmont Development Co., Montana-Tonopah Mining Co. and Midway Mining Co. The production for the

same year approximated $1,500,000, of which about one fourth was gold. Active developments are proceeding and some of the shafts have attained a depth of one thousand feet.

The veins are often faulted in a very complicated manner, well explained by Mr. Spurr in the detailed mine descriptions which occupy one hundred and ninety pages. The explanation of the effect produced on the veins by step faulting along two intersecting systems of dislocation (p. 157 *et seq.*) will be of great interest to many mining engineers.

In such an arid climate, no general basin of ground-water may be expected. Some of the deeper shafts are dry, while in others water was found near the surface, probably in clay-bounded reservoirs.

Preliminary measurements of temperature show an abnormally large increment; the conditions are similar to those of the Comstock.

The paragraphs on oxidation and secondary sulphide enrichment emphasize the necessity of conservatism in prevalent generalizations, especially in reference to the latter subject. Surface oxidation is not deep nor complete and there is but little difference in values and proportion of gold and silver in fresh and altered ore. Secondary sulphide formation is recognized; its products are argentite and pyrargyrite, but they occupy no well defined or greatly enriched zone, and are found in oxidized as well as in fresh ore.

Mr. Spurr believes that chloride of silver may be a primary mineral in part, but this seems to require stronger proof than is given.

Rock alteration and the probable character of the waters that caused it are exhaustively and excellently treated on pp. 207–262. Silicification accompanied by the formation of sericite and adularia and leaching of Ca, Mg and Fe characterize the earlier andesite in the vicinity of the veins, while further away this gradually shades into normal propylitization with the formation of the earthy carbonates and chlorite. It is clearly shown that these two phases are effected by the same mineral waters changed in composition by filtering through the rocks. Mr. Spurr would

eliminate osmotic action, believing the process purely chemical. It is not likely, however, that osmotic action can be dismissed so lightly. Striking differences between vein fillings and altered adjoining country rock and the impermeability of certain wall rocks for gold seem to indicate clearly that dialytic forces are at work.

Mr. Spurr shows that the alteration of the later veins in rhyolite is different from that of the earlier veins. While the earlier waters connected with the more basic andesite were highly charged with silica and potash and were deficient in iron, lime and magnesia, the later waters, connected with the acidic rhyolite, contained carbon dioxide and hydrogen sulphide, with lime, iron and magnesia.

From this remarkable antithesis, from the very peculiar composition of the waters indicated by the prevalence of rare elements, and from several other valid reasons, the vein-forming waters are believed to be of "juvenile" or magmatic origin.

The last chapters emphasize the analogy of the Tonopah deposits with those of the Comstock, Pachuca, Silver City, De Lamar and others in the Cordilleran region. These gold-silver deposits are associated with andesites or rhyolites, and present striking similarities. The somewhat questionable term metallographic province is introduced and is shown in this case to be closely connected with a corresponding petrographic province.

In the last paragraph—on the existence of a major Pacific-Tertiary Petro-metallographic zone—Mr. Spurr, with evident enjoyment, slightly relaxes the tightly held reins of scientific and logical induction, and carries us from Tonopah to the Aleutian Islands, Japan, Krakatoa, Erebus and Terror and the Tierra del Fuego.

The paragraph is, however, very interesting and suggestive and carries the general argument that a large part of the world's supply of silver and gold have been derived from veins in andesites and rhyolites in countries within the ring of Tertiary and Recent eruptions, encircling the Pacific. It becomes impossible to entertain any explanation of the origin of these ore deposits which is based upon processes uniformly distributed through the

world. The world's belt of Tertiary mineralization coincides with the belt of the earth's most active and extensive recent vulcanism.

W. LINDGREN.

Underground Waters of Salt River Valley, Arizona. WILLIS THOMAS LEE, U. S. Geological Survey, W. S. and Irrig. Paper, No. 136. 1905.

This paper is an especially timely contribution to our knowledge of the conditions of underground waters and irrigation in the southwest, since the United States is to provide for a costly reservoir that will directly affect this particular region.

The area described is a "wide aggraded plain," sloping gently westward, from the mountains to the east and north, some thirty-five miles to the junction of the Gila and Salt rivers. From this plain, several outliers, which are probably partly buried remnants of erosion rather than fault-blocks, rise abruptly through the "valley fill." They are made up of Archean granites (biotite); pre-Cambrian quartzites and argillites, that, according to Dr. Walcott, are Algonkian and may, perhaps, be correlated with the Apache series of Ransome in the Tonto basin to the east; "extensive bodies of later eruptives, associated with a limited amount of massive breccias," which are probably Tertiary in age.

The "valley fill," which is the water-bearing horizon over practically the entire area, is Quaternary in age. It is composed of ordinary river debris, angular wash from the neighboring hills and undulating, impervious and more or less continuous sheets of "caliche" (a chemically deposited earthy lime carbonate), sometimes in successive layers but generally following the topography a few inches or feet below the surface. The valley fill is of upland accumulation and is the result of alternating periods of degradation and aggradation, and probably, with other similar areas in the southwest, was caused by "changes in the elevation of the land and by climatic changes." There are two distinct terranes; an older, more consolidated and less pervious gravel-bed which was partly eroded and filled by later and more loosely-compacted water-bearing gravels.

The purpose of the paper was to get the facts concerning the available quantity of underground water, its adaptability for irrigation and the best methods for obtaining it.

From the data secured, it was found that over an area of five hundred and twenty-five square miles there was a definite water-table within fifty feet of the surface, varying somewhat from year to year, where irrigation can profitably be done at a cost of from 5.4 to 13.8 cents per acre-foot per foot of lift, or from $2.50 to about $5.00 per acre foot of water. If electrical power is furnished from some power plant at $50.00 per horse-power, it would reduce the expense to about one fourth its present cost, or to about seventy-five cents per acre-foot. Even now the net profit per acre-foot of water is something between $3.65 and $56.45.

From the data obtained it was found that the underground water flowed through the larger deposits of the coarser boulder-beds in the Mesa region in the southeastern corner of the area, following the old course of the Salt River, which river now flows directly west and has in its newer channel deposited a less extensive bed of the coarser water-bearing gravels in the western half of the area about Phoenix. It is demonstrated clearly that the ground water seeks the old river-channels, though hindered by the intercalated layers of caliche and clay. The close interdependence between the physiography of the past and the occurrence of the ground water of the present is worthy of note. The water-table rises to the surface in the central and western parts of the area (on account of a separating impermeable barrier) with a flow of 100,000 acre-feet per year. The water-bearing stratum is calculated to be some fifteen miles wide in the Mesa region and over two hundred feet deep, which would afford by careful experiment and by using Slichter's formula, from about 150,000 to nearly 300,000 acre-feet per year. This amount of underground water would supply about ninety-six pumping plants, with a capacity of two hundred inches, in continuous operation, without permanently lowering the water-table. The water-table, however, in the past four years has suffered a general depression of from eleven to twenty-two feet. The underground water

appears to come mainly from the river and from occasional hill-floods, with a small "return" from irrigation, though the deep wells (1300 feet) appear to be unaffected by the floods and surface flow. The amount of soluble salts in the river water increases in dry times; but even then it is a half to a third less than the amount in the well-waters, which vary from 75 to 500 parts in 100,000, averaging probably under 300. These salts are calcium, magnesium and sodium carbonates, calcium sulphate and sodium chloride. The latter comes largely from saline springs higher up the river, the others from the leaching of the rocks. The wells after a little use, often freshen as if a pocket of salts had been exhausted; some, however, show an increase.

When there is too large a per cent. of salts in the water, it is mixed with the river water and thus made suitable for irrigation. The writer quotes Professor Forbes's estimate that more than 100 parts of salts in 100,000 "are liable to cause harmful accumulations of alkali." Fortunately the much-feared "black-alkali" (sodium carbonate) is not found in the underflow from which the larger proportion of pumped water is secured, usually only in the surface waters. It might be said, however, that several areas have been irrigated many years without injury with water containing 112–200 parts of soluble salts. In Egypt, moreover, according to the report of Mr. T. H. Means,[1] the *proper* use of waters for irrigation containing as high as 816 parts is not followed by ill effects. He thinks "the amount of soluble matter allowable in an irrigating water has been greatly underestimated by American writers." This view is rather a hopeful one for those who live in some of our arid regions where irrigation has been thought an impossibility. But the *proper* use of these waters should be emphasized.

Concerning the origin of the caliche-beds (not the South American *caliche*, saltpeter or sodium nitrate) which occur throughout certain regions in Arizona and New Mexico and which sometimes divert and retain the underground water under some pressure, though there are no flowing wells in this region, the writer

[1] Bureau of Soils Circular, No. 10, U. S. Dept. Agric., 1903.

gives some excerpts (p. 107, *et seq.*) from Professor Wm. P. Blake's paper[1] on its origin and the theory (perhaps from a chemical standpoint) proposed by Professor E. H. Forbes. The former thinks it is "clearly the result of the capillary flow of calcareous water, induced by constant and rapid evaporation at the surface in a comparatively rainless region." The latter believes the caliche to be the result of the percolating carbonated rain water dissolving some silicates and carbonates (calcium carbonate 72 per cent.; calcium and aluminum silicates 13 per cent.) and evaporating a little below the surface. In certain areas Mr. Lee believes one theory holds good, in another section the other hypothesis, while in a third place some as yet unrecognized cause should be assigned.

In the gathering of the data and the drawing of the conclusions, the practical side is kept plainly in mind and a painstaking care is evident. With regard to the arrangement and form of the report the suggestion might be made that an index map and a customary outline would have been helpful to the reader; that related data should be put on one map; *e. g.*, the prominent wells mentioned, canals, etc., might well have been included on the water-table map; that the geological map, with its very simple geology, might have been on a much smaller scale and perhaps served as an index map and included some important locations, as the Sacaton and Salt River mountains, which cannot be found on any map. Some inaccuracies, probably through inadvertence or haste, makes less valuable some of the diagrams. The section in Fig. 17 probably follows the broken line A-B in Pl. I., but no mention is made of it. Fig. 18 has some references in its description to Fig. 14, but unfortunately nothing is said of it. The vertical exaggeration (2 1/2:1) makes a misleading impression in Fig. 14. In general the diagrams and views are very good and fulfill the author's intentions and the paper is of distinct value to those who have to do with problems of irrigation in the southwest.

C. W. BROWN.

[1] "The Caliche of Southern Arizona," *Trans. Am. Inst. Min. Eng.*, 1901, Vol. 31, p. 220.

Boston Township Iron Range. By WILLET G. MILLER. Report of the Ontario Bureau of Mines, Vol. XIV., 1905. Pt. I., pp. 261–268.

At many places in Ontario iron formation bands and lenses are associated with Keewatin greenstones and green schists, as in the Vermilion district of Minnesota. Mr. Miller reports another of these ranges in the township of Boston in northeastern Ontario. Following the nomenclature of the Joint Geological Committee he finds the succession from the base up: Laurentian granites, Keewatin greenstones, Lower Huronian sediments, trap dikes. The iron formation consists of banded jasper and siliceous material. Its length is approximately six or eight miles and its width from ninety to three hundred feet. Intrusions have cut it to a considerable extent. Mr. Miller's report adds to the literature the description of another area in Ontario in which Lake Superior succession and conditions of iron formation are repeated.

C. K. LEITH.

Economic Geology of the United States. By H. RIES. Pp. xxi + 455: Pl. XXV., with ninety-seven figures in the text. The Macmillan Co., New York, 1905. Also The Macmillan Co., Ltd., London, 1905.

The appearance of a text-book on economic geology in which the precedence is given to the non-metallic products is an innovation that will be welcomed by many students of the subject. Some of us who agree with the author that this arrangement accords with relative importance may be of the opinion, however, that the case of the "non-metallics" is both sufficiently strong and interesting to deserve more than a single sentence and that in the preface. Indeed, the need of an introductory chapter is felt on other accounts. The author's decision not to devote space to a discussion of general geology, mineralogy or physiography appears wise, yet his point of view might very properly be presented to the reader and the province of applied geology outlined. This field has not been covered so thoroughly by literature of

this class that the writer of a general work can afford to take much for granted. The author states that this text-book covers essentially the same ground as the elementary course in this subject at Cornell University. It is probably true, however, that Professor Ries there introduces the subject with one or more general lectures.

This "Economic Geology" purposes to cover in an elementary way all the mineral products of importance in the United States. In general, it can be said that the author has well performed his task, and this book is the most comprehensive and best prepared work on the whole subject, including as it does the non-metallic minerals with the metallic ores. Evidence of the author's wide reading is afforded in the number of journal articles and official reports from which he has gleaned the information presented in this volume. The task of compiling such a work is of necessity a difficult one. Economic geology, both in its scientific and practical phases, is making rapid progress and many investigators find themselves unable to keep pace with the advances along more than a few lines of work. It becomes a debatable question, therefore, whether the best text-book on this subject will ever be written by a single author, or when written, its value can be estimated justly by any one reviewer. Keeping in mind, therefore, this proper realization of the fallibility of both author and reviewer, a few critical suggestions may be considered regarding this work.

The general arrangement of subject matter is attractive and such as to facilitate the use of the volume as a reference work. The list of literature references for each topic is easy of access, but anyone who uses this volume will early learn that these references and the index, while in the main valuable, are not wholly reliable. It is unfortunate to have typographical errors creep into bibliographies and omissions occur in an index. An author may question the degree of accuracy attainable without too great an expenditure of time and energy, but the reader will decide that the limit of practicable revision has not been reached in this volume. Nor are all of the bibliographic errors typographical,

e. g., the reference to Newberry's contribution on the origin of petroleum, twice cited (pp. 47 and 66) as Geological Society of America Bulletin I., page 192, 1887. The reference is plainly wrong, the paper on that subject published by Dr. Newberry nearest that date being in volume VIII. of the *Transactions of the New York Academy of Sciences,* and an earlier reference being Geology of Ohio, I., page 159, 1873. In this connection it may be noted that 1883 (page 39) was not the date for the first attempts to purify petroleum for use as an illuminant. Errors of this grade should be detected by the publisher's proofreader.

The amount of space given to statistical tables for many of the mineral products may seem to some readers somewhat disproportionate. The statistics of production, however, are of special value in the light they throw upon the relative importance of the different minerals and the progress of the industry. Yet, statistics are of most value when exact, and here even typographical errors become of serious moment. These tables, unless otherwise noted, are taken from government reports, as stated in the author's preface. It would have seemed appropriate, however, to include the U. S. Geological Survey Mineral Resources among the references on many subjects, where that report has been plainly an important source of descriptive information as well as of statistical data. In many of these tables of production errors are detected, the worst case, perhaps, being in the section on aluminum and bauxite. Here, not only has the author repeated one error, that a careful reader of the original report would notice, namely, the discrepancy between the values of the United States production of bauxite for 1902 as given in different tables, but he has also introduced several errors of his own making.

The suggestion may be pertinent that the author of a text-book of the grade represented by this volume may reasonably be expected to digest thoroughly the statistics he compiles. A report that is primarily statistical is often of questionable value to the young students of the subject and even older readers, by reason of the overwhelming mass of tabulated figures. It becomes, therefore, the duty of the author of a text-book, which is to be

at once authoritative and readable, to exercise a selective function and to present essential facts only. To best accomplish his purpose he may need to point out in a sentence or two the hidden meaning of certain figures in the accompanying tables, and above all, only the statistics that are of most importance should be quoted and these should be quoted exactly. In many cases this volume reflects such an endeavor on the part of its author, but occasionally he has failed. In the section on mica the author selected the year 1903 for his production statistics. According to the figures available, this year was very exceptional and therefore not the best year for citation, and as it has since appeared these figures were wholly erroneous. To this misfortune in his selection of statistics to be quoted, the author adds the serious mistake of confusing pounds and short tons, in his endeavor to calculate the production of sheet and scrap mica in the same terms. Thus, the production for 1903 is given as 46,693 short tons, an amount probably in excess of the total product of the past century. The value, $59,118, was correctly quoted but the discordance of these figures with past production should have been detected, for even a government report must not be taken wholly on faith. The corrected statistics for the year 1903, as later published, read slightly less than 1970 short tons of sheet, scrap and rough mica, with a value of $143,128. It remains to be noted that the figures for mica imports given as for 1903 are those for 1902.

In other chapters on the non-metallic minerals slight inaccuracies may be noticed; for example, the reference to the evaporation of salt in California as artificial (page 125) and as natural (page 131); the omission of Hallowell, Me., in the mention of monumental granites; and the poorly balanced discussion of precious stones. In the last case, nearly a page is devoted to the ruby, topaz and opal, none of which is found to any extent as a precious stone in this country, while tourmaline, which ranks third as regards value of annual production, is given four words. A more noticeable omission from the list of non-metallic products is feldspar, the annual output of which is valued at over a quarter million. It is especially difficult to account for this neglect, since

no one is better qualified to write on the subject of the feldspar industry than the author.

In the discussion of fissure veins an excellent illustration, Fig. 39, is introduced to show the branching of a vein as it passes from a hard into a soft rock. The figure is credited to Beck (p. 135 not p. 13) who used it to illustrate the passage of a vein from a tough rock, gneiss, into a brittle rock, quartz-porphyry. The present substitution of soft shale for quartz-porphyry in the adapted legend of the figure may possibly be excused by the author's words "after Beck," but inasmuch as the metamorphosed illustration lacks the earmarks of probability, it may be suggested that the use of a wholly ideal sketch might have been a preferable procedure.

The discussion of the origin of the Clinton iron ores appears inadequate. The author's preference for the residual theory seems to be based largely upon a statement of a single observation made nearly twenty years ago. (U. S. Geological Survey Bulletin 52, not 57, as given in list of references.) In view of the thorough studies of Smyth in support of the concretionary origin of these ores, it would seem advisable to secure the more recent data which are available. McCalley (Alabama Survey, 1897, Part II., pp. 69–70) gives figures for the average composition of the hard and soft Clinton ores, which indicate that the too often quoted analysis given by Russell is chiefly remarkable because it is exceptional. The hard ore in the deeper workings, eighteen hundred feet on slope, shows about the same iron-content as ore within two hundred feet of outcrop. Furthermore, these ores from the deep workings are rich enough to furnish 90 per cent. of the furnace burdens in the Birmingham district. The difference between the hard and soft ores is not simply in relative proportions of iron and lime, but there is also on the average twice as much silica in the soft ore as in the hard ore. These chemical relations may be taken as indicating a surface leaching of the lime and a greater concentration of the silica and a less concentration of the iron oxide, but this does not explain the workable ores below the surface zone as of residual origin. The author has transposed on page 267 "hard" and "soft" in the

designation of two ores, analyses of which are given on the following page. Some readers might also desire to know the source of these two analyses.

Another reviewer (*Am. Geol.*, XXXVI., p. 322) has noted some inaccuracies in the chapter on copper, a subject on which that reviewer is an especially competent critic. It may be added here that the omission of covellite from the list of ore minerals does not seem justified. While somewhat rare as a copper ore, it is hardly of less importance than melaconite which is included in the list. Moreover, the author mentions covellite as a copper ore at least three times on following pages. In the table of production Eastern Atlantic States is not a wholly happy term for the group in which Tennessee is the largest producer.

The chapter on gold and silver lacks the clear-cut analytical treatment so characteristic of the article by Lindgren, largely followed by the author. Moreover, the typographical expression of the areal grouping of gold and silver occurrences is decidedly bad and confuses the reader who wishes to keep in mind the author's analysis. In describing the Tintic ores (page 372) the author cites the "average assay of 240,000 tons"; the correct statement would have been the "average content or yield of 240,000 tons," since the percentages quoted were based upon actual production returns. The literature references in this chapter are more generously distributed than is the noble metal itself, the articles cited on Oklahoma and New England being descriptive of the non-occurrence of gold. Other references show a lack of discriminating selection; for example, under Washington, a reconnaissance description of a district then of only prospective development is included while a more thorough report by the same geologist on a producing district is omitted.

In conclusion, the reviewer wishes to repeat his appreciation of the difficulties of book-making. In fact, his purpose in this critical examination of the work here discussed has been twofold: first, to call attention to obvious errors and to indicate different points of view; but in the second place to do what seems more timely, to plead the importance of the subject of economic geology and to suggest the grade of treatment it deserves both

by the investigator-writer and the text-book author. In no subject is quantitative exactness more essential.

G. O. SMITH.

Underground Water Literature Published in the United States in 1905. By M. L. FULLER, F. G. CLAPP and B. L. JOHNSON, U. S. Geol. Survey, Water Sup. and Irrig. Paper, No. 163. Pp. 130.

That hydrology has been attracting much attention in recent years is evidenced by the 530 titles noted in this bibliography. If a corresponding list of foreign papers were available it would be even more evident. A few years ago only the most meagre data were available for any study of underground waters. Aside from artesian wells, which were understood in a general way, little was really known about the flow of water below the surface. Such questions as relate to the lower limit of the ground water, the amount and character of magmatic waters, the loss of water in consolidation of marine sediments, the rate of underground flow, the character and number of channels through which it passes, the depth to which bacteria may penetrate, and all the range of problems growing out of the chemical activities of the waters were not at all appreciated, and many of them had not even been raised. To-day we know something about the questions if not the answers, and this bulletin indicates that we may shortly expect the data for the solution of at least a part of them.

The great range of information and the extent to which it is scattered through periodicals little read by ordinary geologists is strikingly shown. For these reasons the unusually full abstracts given are especially valuable. They seem to have been made with unusual care and present real information regarding the papers reviewed. A valuable index is included so that material may be found either by subject or area.

H. F. BAIN.

RECENT LITERATURE ON ECONOMIC GEOLOGY.

COMPILED BY

A. H. HUGHEY AND F. L. RANSOME.

Aarbog for 1905. No. 43, Norges Geologiske Untersogels, Kristiana, 1905.

Action de l'hydrogène sulfuré sur quelques oxydes métalliques et Metallordïques. Applications aux phénomènes volcaniques st aux eaux thermales. By ARMAND GAUTIER. Comptes Rendus, Vol. 142, 1906. Pp. 7–12.

Action de l'Oxyde de Carbone, au Rouge, sur la Vapeur d'Eau, et de l'Hydrogene sur l'Acide Carbonique. Application des ces Reactions á l'Etude des Phenomenes Volcaniques. By ARMAND GAUTIER. Comptes Rendus, Vol. 42, 1906. Pp. 1382–1387.

Aids in Practical Geology. By GRENVILLE A. J. COLE. With numerous illustrations. 5th ed., revised. London, 1906. Pp. 431.

Artesian and other deep wells on the Island of Montreal. By FRANK D. ADAMS and OSMOND E. LEROY. McGill University. 74 pages, with plates. Papers from the Department of Geology, No. 21 (reprinted from the Ann. Report of the Geol. Survey of Canada, Part O, Vol. XIV). Montreal, 1906.

Beiträge zur Kenntnis der Huelvaner Kieslagerstätten. By BRUNO WETZIG. Zeitschift für praktische Geologie, Vol. 14, 1906, pp. 173–186.

Bibliographic Review and Index of Underground Water Literature Published in the United States in 1905. By MYRON L. FULLER, FREDERICK G. CLAPP and BERTRAND L. JOHNSON. U. S. Geol. Survey, Water Supply and Irrigation Paper, No. 163, 1906. Pp. 130.

Bibliography of Clays and the Ceramic Arts. By JOHN C. BRANNER. Pp. 1–451. American Ceramic Society, 1906.

Bodenschätze und Bergbau Kleinasiens. By C. SCHMEISSER. Zeits. f. prak. Geologie, Vol. 14, 1906, pp. 186–196 (with map showing occurrence of useful minerals in Asia Minor).

Boletin de la Secretaria de fomento, Año V., Numero II., foleto, II., June, 1906. Mexico. Pp. 707–762.

Boletin de la Sociedad nacional de minera, Revista Minera, Año IX., Nos. 97 and 98, Lima, January 31 and February 28, 1906. Also Año VII., No. 96, 1905. Año VIII., No. 95, 1905.

Carboniferous of the Appalachian Basin. By JOHN J. STEVENSON. Bull. Geol. Soc. Amer., Vol. 17, pp. 65–228. Rochester, May, 1906.

Coal Fields of the Kachenak Bay Region. By RALPH W. STONE. U. S. Geol. Survey, Bulletin 277, 1906.

Coal Resources of the United Kingdom. By J. L. PULTZ. Engineering and Mining Journal, Vol. 82, 1906, pp. 17–18. Notes from the final report of the Royal Commission on Coal Supplies, 1905.

Copper Deposits of New Jersey. By N. S. KEITH. Mining Magazine, Vol. 13, 1906. Pp. 468–475. Illustrated.

Einige Bemerkungen über afrikanische Erzlagerstätten. By R. BECK. Zeitschrift für praktische Geologie, Vol. 14, 1906. Pp. 205–209 (tin and gold).

Eisenerzlagerstätten bein Kiruna. By O. STUTZER. Zeitschrift für praktische Geologie, Vol. 14, 1906. Pp. 140–142.

Eisenerzlagerstätte "Gellivare" in Nordschweden. By O. STUTZER. Zeits. f. prak. Geologie, Vol. 14, 1906. Pp. 137–142.

Erläuterungen zu Blatt Saarbrücken der Geologischen Übersichtskarte von Elsass-Lothringen. By DR. L. VAN VERVEKE. Strassburg, 1906. Pp. 284.

Estadistica minera de Espana, correspondiente al ano de 1905, formada y publicada por la Inspeccion general de Mineria. Madrid, 1906. Pp. 167.

Étude sur l'état actuel des mines du Transvaal. Les gites — leur valeur, étude industrielle et financiere. By GEORGE MOREAU. (Ch. Beranger), Paris, 1906. Pp. 218.

Genèse des eaux thermales et ses rapports avec le volcanisme. By ARMAND GAUTIER. Annales des Mines, 6th ser., Vol. 9, 1906. Pp. 316–370.

Geology and Coal Resources of the Cape Lisburne Region, Alaska. By ARTHUR J. COLLIER. U. S. Geological Survey, Bull. No. 278. Washington, 1906. Pp. 1–50, with nine plates.

Geology and Mineral Resources of the Norseman District, Dundas Gold Field. By W. D. CAMPBELL. Western Australian Geological Survey, Bull. 21, 1906. Pp. 140, with geological map, 5 plates and 19 figures.

Geology of the Country near Sidmouth and Lyme Regis. By H. B. WOODWARD, F.R.S., and W. A. E. USSHER, F.G.S. Memoirs of the Geological Survey, England and Wales. Explanation of sheets 326 and 340. London, 1906. Pp. 96, with plates.

Geology of the Owl Creek Mountains. By N. H. DARTON. Doc. 219, 59th Congress. 1906. Pp. 47, with plates.

Geology of the State of Panna, Principally with reference to the Diamond-bearing Deposits. By E. VREDENBURG, A.R.C.S. Records of the Geological Survey of India, Vol. XXXIII, Part 4, 1906. Calcutta, 1906. Pp. 261–314, with plates 25 and 26.

Gold Mines of Formosa. By ACTING CONSUL CROWE. Mining Journal, Vol. 79, 1906. Pp. 722–723.

Gold Mining at Bidi, Sarawak. By T. C. SCRUTTON. Mining World, Vol. 25, 1906. Pp. 63–64.

Hot Springs at Thermopolis, Wyoming. By N. H. Darton. Journal of Geology, Vol. 14, 1906. Pp. 194–200.

Investigation into the Elastic Constants of Rocks, more especially with reference to cubic compressibility. By FRANK D. ADAMS and ERNEST G. COKER. Carnegie Institution, publication No. 46. Washington, D. C., 1906. Pp. 69, 16 plates and 26 text-figures.

Irrigation in the United States. By F. H. NEWELL. 433 pages with plates. 1906.

Jeolojia. By IGNACIO DOMEYKO. Tomo quinto. 457 pages with plates. Santiago de Chile, 1903.

Limestones, Associated with Pyrites and Pyrrhotite of the Appalachian System. By FRANK L. MASON. Eng. and Mining Journal, Vol. 82, pp. 170–172.

Mica dans la province de Quebec, Canada. By J. OBALSKI. Department de la colonization et de mines, 63 pages. 1903.

Mineral Pigments of Canada. By C. W. WILLIMOTT. Geol. Survey of Canada, Bull. No. 913, 39 pages. Ottawa, 1906.

Mineral Resources of Kenai Peninsula, Alaska: Gold Fields of the Turnogain Arm Region. By FRED. H. MOFFITT. U. S. Geol. Survey. Bulletin No. 277, 1906. Pp. 80, maps and illustrations.

Mineral Resources of the United States for 1905. Chapters on abrasive materials, 21 pages; talc and soapstone, 12 pages; precious stones, 40 pages; Monazite, zircon, gadolinite and tantalum minerals, 7 pages; asbestos, 7 pages. U. S. Geological Survey, 1906.

Minerals and Metals. By J. G. GOESEL. 287 pages. John Wiley and Sons, New York, 1906.

Mining and Quarry Industry of New York State, Report of Operations and Production in 1905. By D. H. NEWLAND. Bull. 102. Economic Geology 15, New York State Museum. 1906. Pp. 199.

North Laramie Peak Copper District in Converse, Albany and Laramie Counties, Wyoming. By HENRY C. BEELER. State Geologist. 16 pages. Cheyenne, July 1, 1904.

Note on Mining in Siam, 1904. Reprint from copyright publications of Royal Commission for Louisiana Purchase Exposition.

Notes on the Geology and Mineral Resources of the Narnaul District (Patiala State). By P. N. BOSE. Records of the Geological Survey of India, Vol. 3, Pt. 1, 1906. Pp. 55–61.

Notes on the Petrology and Manganese ore Deposits of the Sansar Tahsil, Chhindwára District, Central Provinces. By L. L. FERMOR. Records of the Geological Survey of India, Vol. 33, Pt. 2, 1906. Pp. 159–220, with 7 plates.

Oil Fields of the Texas-Louisiana Gulf Coastal Plain. By N. M. FENNEMAN. U. S. Geol. Survey, Bull. 282, 146 pages, with maps and illustrations. Washington, 1906.

Oil Fields of Trinidad. By E. H. C. CRAIG. Mining Journal, Vol. 80, 1906. Pp. 6 and 36–37.

Om Torvmyrer in Norge, No. 38 Norges Geologiske Untersogelse. By G. B. E. STRANGELAND. 132 pages with plates.

Origin of "Washouts" in Coal Mines and their Relation to other Features of the Transvaal Coal Measures. By E. T. MELLOR. May, 1906. Trans. Geol. Soc., South Africa. Pp. 74–81.

Physiography of the River Nile and its Basin. By CAPT. H. G. LYONS. Finance Ministry, Survey Department, Cairo, 1906. Pp. 411, map of Nile Basin, and 48 plates.

Preliminary Report on a Part of the Clays of Virginia. By HEINRICH RIES. Geological Series, Bull. 11, Geological Survey of Virginia, 1906. Pp. 184, with plates and map.

With a chapter on the geology of Virginia Coastal Plain by W. B. Clark and B. L. R. Miller.

Preliminary Report on Roswell Artesian Area. By CASSIUS A. FISHER. Water-supply Paper, No. 158, U. S. Geological Survey. 1906. Pp. 29.

Preliminary Report on the Peat Resources of Iowa, and Report on Tests of Iowa Coals at Coal Testing Plant at St. Louis in 1904. By T. E. SAVAGE. Bull. No. 2, Iowa Geological Survey, 1905.

Preliminary Report on the Rossland, B. C., Mining District. By R. W. BROCK. Geol. Survey of Canada, Bull. No. 939. 40 pages. Ottawa, 1906.

Production of Arsenic in 1905. By C. C. SCHMATTERBECK. Extract from Mineral Resources of the U. S., calendar year 1905. U. S. Geol. Survey, Washington, 1906.

Progress of the Mineral Industry of Tasmania for Quarter Ending March 31, 1906. By W. H. TWELVETREES. 1906. 14 pages. Tasmania.

Rampart Gold Placer Region, Alaska. By L. M. PRINDLE and FRANK L. HESS. Bull. No. 280, U. S. Geol. Survey. 54 pages, 7 plates. Washington, 1905.

Reclamation of Alkali Soils. By CLARENCE W. DORSEY. Bull. No. 34, U. S. Dept. Agric., 1906. 30 pages, with plates.

Recursos minerales de Jauja y Huancayo. By ENRIQUE L. DUEÑAS. No. 35. Boletin del Cuerpo de Ingenieros de Minas del Peru. 120 pages with plates. Lima, 1906.

Region cuprifera de los Alrededores de Ica y Nazca. Por Federico G. Fuchs. Boletin del Cuerpo de Ingenieros de minas del Peru, No. 29. 100 pages with plates. Lima, 1905.

Register of Oil Wells, Los Angeles County, California. State Mining Bureau. 1903.

Relations Between Gold and Pyrite. By H. L. SMYTH. Mining and Scientific Press, Vol. 93, 1906. Pp. 58–59, with text-figures.

Report of Mineral Statistics and Mines for 1900, Geological Survey of Newfoundland. By JAMES P. HOWLEY. 39 pages. 1901.

Report of Mineral Statistics for 1899, Geological Survey of Newfoundland. By JAMES P. HOWLEY. St. John's. 18 pages. 1901.

Report of Mineral Statistics for 1905, Geological Survey of Newfoundland, and Report of Coal-boring Operations near Goose Brook, Humber Valley. By JAMES P. HOWLEY. 39 pages. 1901.

Report of the Bureau of Mines, 1904. By THOS. W. GIBSON, Director. Pp. 1–255, with plates and maps. L. K. Cameron, Toronto, 1904.

Report on the Chibougaman Mining Region in the Northern part of the Province of Quebec. By A. P. Low, B.S., F.R.G.S. Geol. Survey of Canada, Bull. No. 923. 60 pages, with map. Ottawa, 1906.

Report on the Mathinn Goldfield. By W. H. TWELVETREES. Part 1, 44 pages, with plates. Tasmania, 1906.

Report on the Tin-mining District of Ben Lomond. By GEORGE A. WALLER. 41 pages, with plates. Tasmania, 1901.

Salt. By F. E. ENGLEHART. Technology Club, Syracuse, N. Y.

Some Local Effects of the San Francisco Earthquake. By STEPHEN TABER. Journal of Geology, Vol. 14, 1906. Pp. 303–315, illustrated.

South Pass Gold District, Fremont County, Wyoming, Second Edition. By HENRY C. BEELER, State Geologist. 16 pages. July 15, 1904.

Sul giacimento di galena argentifera dell' altipiano di Cadlimo. By E. MARIANA. Giornale di geologia practica. Ann. IV., fasc. II–III, 1906. Pp. 94–98.

Supplementary Report on Portland Cement Materials in Iowa. By S. W. BEYER. Bull. No. 3, Iowa Geological Survey. 36 pages. Desmoines, 1906.

Supplementary Report on the Composition and Quality of a Series of Indian Coals. By PROF. WYNDHAM R. DUNSTAN, M.E., LL.D., Records of the Geological Survey of India, Vol. XXXIII., Part 4, 1906. Pp. 241–253. Calcutta, 1906.

Transaction of the Manchester Geological and Mining Society, 1905–06. Part VI., Vol. XXIX. 364 pages. Manchester.

Twelfth Report of the Ontario Bureau of Mines, 1903. By THOS. W. GIBSON, Director. Pp. 1–354, with 56 plates and 21 maps. L. K. Cameron, Toronto, 1903.

Twenty-fourth Annual Coal Report of Bureau of Labor Statistics of Illinois, 1905. 412 pages. 1906.

Uber Grunddwasserverhältnisse in der Umgebung von Bregenz am Bodensee. By J. BLAAS. (Map and figures in text.) Zeits. f. prak. Geologie, Vol. 14, 1906. Pp. 196–205.

Underground Water in the Valleys of Utah Lake and Jordan River, Utah. By G. B. RICHARDSON. Water-supply and Irrigation Paper, No. 157, U. S. Geol. Survey. Pp. 81, illustrated. Washington, D. C., 1906.

Volcanoes and Radioactivity. By MAJ. C. E. DUTTON. U. S. A. Journal of Geology, Vol. 14, 1906. Pp. 259–268.

Water Supply of Suffolk from Underground Sources. By WILLIAM WHITAKER and others. Memoir of the Geological Survey of England and Wales. 177 pages and map. London, 1906.

Yaciimentos de Fierro de Alja y Calleycancha. Por LUIS PFLÜCHER. Lima, 1905. No. 36, Boletin del Cuerpo de Ingenieros de Minas del Peru. 33 pages.

Zinc and Lead Deposits in Wisconsin. By U. S. GRANT. Mining Magazine, Vol. 13, 1906. Pp. 453–460, illustrated.

Zinc Industry in the United States. By H. S. CLARK. Mining Magazine, Vol. 13, 1906. Pp. 461–467.

SCIENTIFIC NOTES AND NEWS[1]

NOTWITHSTANDING THE REDUCTION OF THE HYDROGRAPHIC APPROPRIATION by Congress, the underground water studies of the United States Geological Survey will be conducted as usual this season, the investigations covering even more territory than in the previous year. Work is now under way in Maine, Connecticut, Virginia, Florida, Kentucky, Ohio, Indiana, and Iowa; and will be extended to New York, Pennsylvania, North Carolina, South Carolina, and Minnesota later in the season. Mr. M. L. Fuller will supervise investigations in these states as in the past.

MR. SAMUEL SANFORD is engaged in an investigation of the underground waters of the Coastal Plain of Virginia for the United States Geological Survey. The developments in this important region have been very marked since the report of N. H. Darton in 1896 and the demand for information very great, especially in regard to the quality of the water and its availability for boiler and industrial purposes. To supply this, complete chemical studies will be undertaken as a part of the work.

MR. M. L. FULLER, in addition to the supervision of the underground water work of the United States Geological Survey in the eastern United States, will spend a portion of the field season in an investigation of the underground waters of the Cincinnati region and adjacent portions of Ohio and Indiana. Associated with him will be Mr. F. G. Clapp and S. R. Capps. The work will include studies of the rock waters and the waters of the drift, and will be both geological and chemical.

PROF. H. E. GREGORY, of Yale, is devoting a part of the present field season to the completion of an investigation of the underground waters of Connecticut for the United States Geological Survey. The studies of the waters of crystalline rocks has already been completed, leaving only the limestones and

Triassic rocks to be examined. A large number of analyses will be made of typical waters with a view of determining their suitability for public supplies, for use in steam boilers, or in industrial processes.

S. F. EMMONS, G. F. Becker, T. C. Chamberlin, W. Lindgren, Geo. Otis Smith and F. L. Ransome have been appointed delegates from the U. S. Geological Survey to the Tenth International Geological Congress.

MR. J. E. SPURR, who has been in Washington for the past few months, finishing his report on the Georgetown District, Colo.. for the U. S. Geological Survey, expects to return to Mexico shortly and resume his work for the Guggenheim companies.

MR. J. M. BOUTWELL, who is in charge of the collection of lead and zinc statistics for the U. S. Geological Survey, is ill with typhoid fever in Denver, Colo.